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A COST ESTIMATION MODEL FOR THE
SEA LAUNCH AND RECOVERY
SPACE TRANSPORTATION SYSTEM

by

Layne Renée Boone

September, 1990

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The purpose of this thesis is to provide a cornerstone for the design of such a cost estimation model. The model presented here can be used to compute the minimum cost per mission as a function of selected design variables. The particular variables considered are the type or types of materials used in the fuel tanks of the rocket and characteristics of the fuel logistics, such as port locations. Thus, it is a tool to be utilized by the system designers in judging the value of particular rocket fuel tank designs. It can also aid in the selection of the operational port for the system.
Implementation issues are discussed and evaluated. Future enhancements to the model are also discussed.

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A Cost Estimation Model for the
Sea Launch and Recovery Space
Transportation System

by

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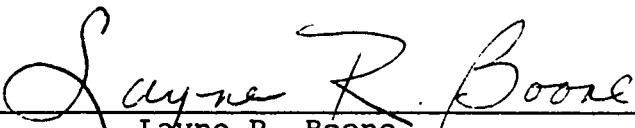B.A., Fisk University, 1970
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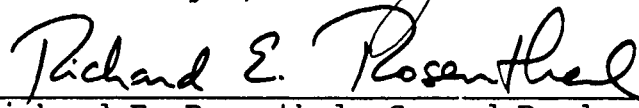
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ABSTRACT

The Sea Launch and Recovery Space Transportation System is envisioned as a means of achieving not only more effective but lower cost space operations. The development of a cost estimation model is important in determining the feasibility of this system.

The purpose of this thesis is to provide a cornerstone for the design of such a cost estimation model. The model presented here can be used to compute the minimum cost per mission as a function of selected design variables. The particular variables considered are the type or types of materials used in the fuel tanks of the rocket and characteristics of the fuel logistics, such as port locations. Thus, it is a tool to be utilized by the system designers in judging the value of particular rocket fuel tank designs. It can also aid in the selection of the operational port for the system.

Implementation issues are discussed and evaluated. Future enhancements to the model are also discussed.

THESIS DISCLAIMER

The reader is cautioned that the computer program developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the program is free of computational and logic errors, it can not be considered valid. Any application of this program without additional verification is at the risk of the user.

TABLE OF CONTENTS

I. INTRODUCTION

The Naval Center for Space Technology of the Naval Research Laboratory is conducting a research and development program into the properties of a family of reusable rockets that are launched from the ocean. The feasibility of a space transportation system using these Sea Launch and Recovery (SEALAR) rockets is of interest to the Secretary of the Navy, the Director of the Navy Space Systems Division of the Office of the Chief of Naval Operations , and the Senate Armed Services Committee. Such a space transportation system, henceforth to be referred to as the SEALAR Space Transportartion System (SSTS), could be used to provide military and commercial access to space under either war or peacetime conditions from the ocean. Space access would not be limited by the restrictions now placed upon land-based launch sites.

The SSTS was first conceived in the late 1950's. In the 1960's it received extensive study by Aerojet General under a contract to NASA's Marshall Space Flight Center. A series of new detailed investigations was initiated in February 1988 by the Naval Center for Space Technology. The technical feasibility of rocket recovery without extensive damage to the rocket stages, hence reusability, is currently under study. However, the economic competitiveness of the SSTS hinges on more than reusability. It also depends on total research and development and operational costs. [Ref. 1]

The SSTS is a system being designed to provide low cost-per-mission, low cost-per-pound orbited, and a known service delay for its users. In order to

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successfully accomplish these objectives, the designers need mathematical tools to aid them in their analyses.

It is the intention of this thesis to provide a design for a means for judging the value of particular rocket fuel tank designs. This tool can then be used by the SSTS designers to assess those costs for their potential customers. It will also be useful in determining which port of operation would be most cost efficient in terms of these fuel tank costs and the port operating costs. This model will be a cornerstone upon which a complete SSTS cost estimation model can be built. The conceptual basis for this tool was provided by the major developers of the SSTS, Truax Engineering, Inc.

The second chapter deals with the background of the SEALAR Space Transportation System. The motivation for this type of space transportaion system is discussed. The SSTS is described followed by the history of the SEALAR rockets.

Chapter III presents the concept of operations of the SSTS. This involves describing the relationships between the operational functions of the system.

The fourth chapter describes the optimization model used to minimize the cost of the SEALAR rocket fuel tanks for the SSTS. It is the tool with which the SSTS designers can readily determine which fuel tanks are most cost efficient. It also can be used to determine the most cost efficient port of operation since it provides the cost per mission of operating at each port based on these fuel tank costs and the port operating costs.

Chapter V is an analysis of the fuel tank and operating cost estimation model. Variations of the model are discussed and analyzed.

II. BACKGROUND

A. MOTIVATION

The military is a major developer and user of space. Its missions include space support in environment, navigation, communication, and surveillance. Space control and space warfare are also of paramount importance to military strategists. In this regard, there is a national need for not only more effective but lower cost space operations.

There are three possible ways in which to achieve this goal. The first is to reduce the cost of the space transportation system. Although a reduction in cost per launch could be realized by reducing the transportation system cost, this may require several launches to recoup the initial investment made during the development of such a system. This inevitably leads to the question of how many launches will be required in the forseeable future, a question which may be difficult to answer. The second alternative is to reduce the cost of the satellite. There is no evidence to date that this can be accomplished because of the reliability constraints which face the satellite engineers. However, if it were possible to carry more weight to orbit at a lower cost and to go to orbit at any time to repair or replace satellites, then the building of a cheaper satellite would become feasible. This leads to the third alternative, reducing the cost of both the satellite and the space transportaion system. The Sea Launch and Recovery Space Transportation System is a possible means of accomplishing this goal.

The Sea Launch and Recovery Space Transportation System (SSTS) was originally conceived and its development is currently being studied by the Naval

Center for Space Technology. These studies are based on the premise that a major reduction in space launch costs can be attained at a reasonable research and development cost. The motivation for these studies, at least in part, is the possibility that a reasonably effective defense against intercontinental ballistic missles (ICBMs) will also require that large amounts of equipment be placed in earth orbit. The SSTS could also provide transport to orbit for non-strategic defense missions or to locations on the earth along suborbital trajectories. It could be used for commercial as well as military satellite launches under conditions of peace and war. Some of the payloads for which the SEALAR Space Transportation System could be used for economically competitive transport are:

- satellites of 10,000 lbs and up being launched into earth orbi′

- cargo in support of space exploration missions, such as fuel for a planetary exploration program

- ordnance delivery for AAW, ASW, ASUW, strike and amphibious missions of the U. S. Navy

- urgently needed cargo to distant points on the earth.

If the cost could be reduced sufficiently, a large, reusable space launch vehicle would also have the ability to serve as a non-nuclear ICBM.

B. DESCRIPTION OF THE SSTS

The SEALAR Space Transportation System is composed of two subsytems: the rocket subsystem and the support subsystem. The rocket subsystem is based on a family of liquid-fueled, ocean-launched and recovered rockets. The support subsystem can be briefly defined as that part of the SSTS which encompasses the reception and preparation of the payload, the transport of the mated rocket to the

launch site, the actual launching of the rocket and its tracking and safety control during flight as well as the rocket recovery and refurbishment.

It is the ocean-launch capability that would eliminate several of the constraints and costs now associated with land-based launch. There would be less concern for launch pad vulnerability and/or survivability since the launch platform would be mobile and less susceptible to such damage. In addition, since the launch would be from open ocean, range safety concerns such as overflight of populated areas would be far less stringent than on land. By design, there would be limited environmental impact. Unlike land-based launches, the weather conditions during a SSTS launch could range from heavy to benign seas, winds, and precipitation.

The SSTS would also be advantageous because of its potentially low cost. This cost is a function of the fuels and rockets utilized. Reduced costs would be a result of the use of rockets that are recoverable and refurbishable. The fuels utilized by the SSTS can be easily replenished without major refurbishment to the rocket. Additionally, these propellants are not only inexpensive but environmentally safe and plentiful. This contributes to the effectiveness, in addition to the economy, of the system.

C. ROCKET SUBSYSTEM

In the early sixties, cost was a dominant consideration as the National Aeronautics and Space Administration (NASA) looked for ways to make a manned mission to Mars and a manned lunar base economically feasible. Two important conclusions were reached regarding the root causes of the high cost of space transportation. The first of these was that costs vary only slowly with size, but very sharply with complexity and reliability. The other was that a large fraction of the

cost of a space launch vehicle resided in the propulsion hardware that was discarded. [Ref. 2]

Based on the philosophy that a low-cost launch vehicle, therefore, should be big, simple, reusable, and use existing state of the art technology wherever possible, Aerojet-General Corporation conducted a project. This project resulted in a design that had the lowest cost predicted for any configuration. The design was dubbed the Sea Dragon and cost less than one hundred dollars per pound of payload delivered to orbit (in FY1963 dollars). The economy of the Sea Dragon was obtained not through ever-increasing sophistication but through its great size, simplicity, and reusability. [Ref. 2]

The Sea Dragon was of a size large enough to fulfill all of the foreseen missions. Its design embodied those characteristics required of a low-cost vehicle:

- It was big; it was capable of lifting to low orbit nearly one million pounds of payload per flight.

- It was simple; only two pressure-fed stages were used to attain low earth orbit (LEO). Each stage had only one main propulsion engine. Propellants used in the first stage were kerosene and liquid oxygen, in the second, oxygen and hydrogen.

- It was reusable; the simplest and lightest means available to return the stages to earth were used: a parachute-like drag device on the first stage, and a heat shield plus drag device on the second.

- It was sea launched; it was built in a drydock, towed to a lagoon, checked out dockside, fueled at sea, erected by a flooding ballast, and launched directly out of the water.[Ref. 3]

A small fleet of Sea Dragons would be capable of satisfying, in an economic fashion, all of the major space missions seriously considered to the current date, including the manned space station, the orbiting solar power station, a manned lunar base, and the Manned Mission to Mars.

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Truax Engineering designed a pressure-fed, liquid propellant rocket called the Excalibur in the seventies. The Excalibur is a smaller version of Sea Dragon, having a liftoff weight of 3.6 million pounds and a payload of 100,000 pounds.

To reduce some of the design and competitiveness issues raised by the Sea Dragon launch vehicle concept, Truax Engineering was commissioned by the Naval Center for Space Technology to do a design study in 1988 of an even smaller version of the Sea Dragon. This new design, the SubCalibur, is only one-eightieth the size of Sea Dragon but is large enough to carry the largest Navy payload expected in the next ten years, and it embodies most of the technical features of Sea Dragon.

The SubCalibur rocket is a two-stage launch vehicle designed for minimum whole life cost over a ten year life. The first stage employs liquid oxygen and kerosene while the second stage employs liquid oxygen and liquid hydrogen. Both stages are pressure-fed with a single main engine per stage and both are recoverable in the ocean by drag devices only. The SubCalibur has the capability of launching 10,000 pounds of payload into low earth orbit (LEO) from land or sea. [Ref. 1]

Recently, Truax Engineering, in cooperation with the Naval Center for Space Technology, developed three near scale models of the first stage of an operational vehicle incorporating the design philosophy and most of the design features of the Sea Dragon, the X-3, X-3A and X-3B. The X-3 uses the same propellants, the same tank materials, but a different recovery system as proposed for the fully operational vehicle. Use of the X-3 will help to verify the design features of a water-launched, reusable first stage and, through repeated launches and recoveries, provide experience from which more accurate estimates of turn-around costs may be made. The X-3A and X-3B, redesigned versions of the X-3 rocket, are more faithful scale

models of SubCalibur and use high speed recovery. There are also plans for test vehicles larger than the X-3 family but smaller than Excalibur. [Ref. 1]

The Sea Launch and Recovery Space Transportation System is based upon the family of rockets comprising those just described. The SEALAR rockets will be used to determine the effectiveness of this transportation system in terms of cost per pound of payload delivered reliably to the desired destination. The cost per mission will also be used to define the system's feasibility.

III. OPERATIONAL CONCEPT

The operational concept, introduced by Aerojet-General Corporation in the form of the Sea Dragon and being further developed by NRL and Truax Engineering, basically uses mature technology in new ways. These new techniques include but are not limited to:

- economically launching from a floating position in the ocean

- ballistic recovery in the ocean at speeds up to perhaps as high as 300 feet per second with reusability of recovered components

- use of maraging steel or other high strength materials for tankage.[Ref. 1]

Sea launch is favored due to the ability to handle very large vehicles by exploiting buoyancy. It also provides great flexibility in launch location. In a military situation, this flexibility gives greater utility and lowered vulnerability to enemy countermeasures.

The Sea Launch and Recovery Space Transportation System will consist of a two-stage rocket where the second stage is capable of going on orbit. The vehicle will be prepared dockside with fueling dockside, at sea, or a combination of the two. After dockside checkout, the rocket is towed to sea by one or more tugs.

Following the erection of the rocket by flooding the ballast, it is launched from the ocean near the continental United States. The first stage will land less than two hundred miles down range after a ballistic reentry. It is subsequently retrieved by a tug and returned to the launch point for refurbishment and reuse.

The second stage will separate from its payload, make several orbits of the earth until it is in a favorable position, and then de-orbit at the proper time to enable impact less than two hundred miles from the launch site. A drag device and a relatively

small amount of heat protection is all that would be required to accomplish this. The second stage is retrieved from the ocean in the same manner as the first. Turn-around times on the order of a few days do not seem impossible for this launch vehicle since liquid propellant rockets should be more easily refurbished than solid propellant rockets.

This concept of operations for the Sea Launch and Recovery Space Transportation System can be depicted using the structured analysis flowchart technique. This is a technique by which a system is broken down into successively smaller, well-defined modules. [Ref. 4]

The top diagram in Figure 1 establishes the model of the launch service operation of the SSTS. The viewpoint taken is that of the SSTS operations manager. The operations manager is faced with several tasks based upon a customer's request. These include, but are not limited to, the number of rockets required to deliver the specified payload into the desired orbit, the amount of fuel required for the particular type of rocket, and the amount of time required to perform all of the necessary operations prior to and following the launch. In order to accomplish his tasks, the operations manager needs to know the customer's requirements (C1) as well as rocket requirements (C3). Space launches must also proceed according to specific launch procedures (C2).

Transporting a payload to orbit involves five major operations as depicted at the bottom of Figure 1. The first and certainly one of the most important steps is the interpretation of the customer's requirements (A1). Once these have been determined, the operations manager must determine the "cargo" necessary to accomplish the customer's mission. Table 1 illustrates some possible components of the "cargo". It is then the responsibility of the operations manager to transport the

cargo to the marshalling site (A3) after its arrival at the port (A2). Once the payload is actually launched (A4), the rockets must be recovered and refurbished (A5) in preparation for subsequent launches.
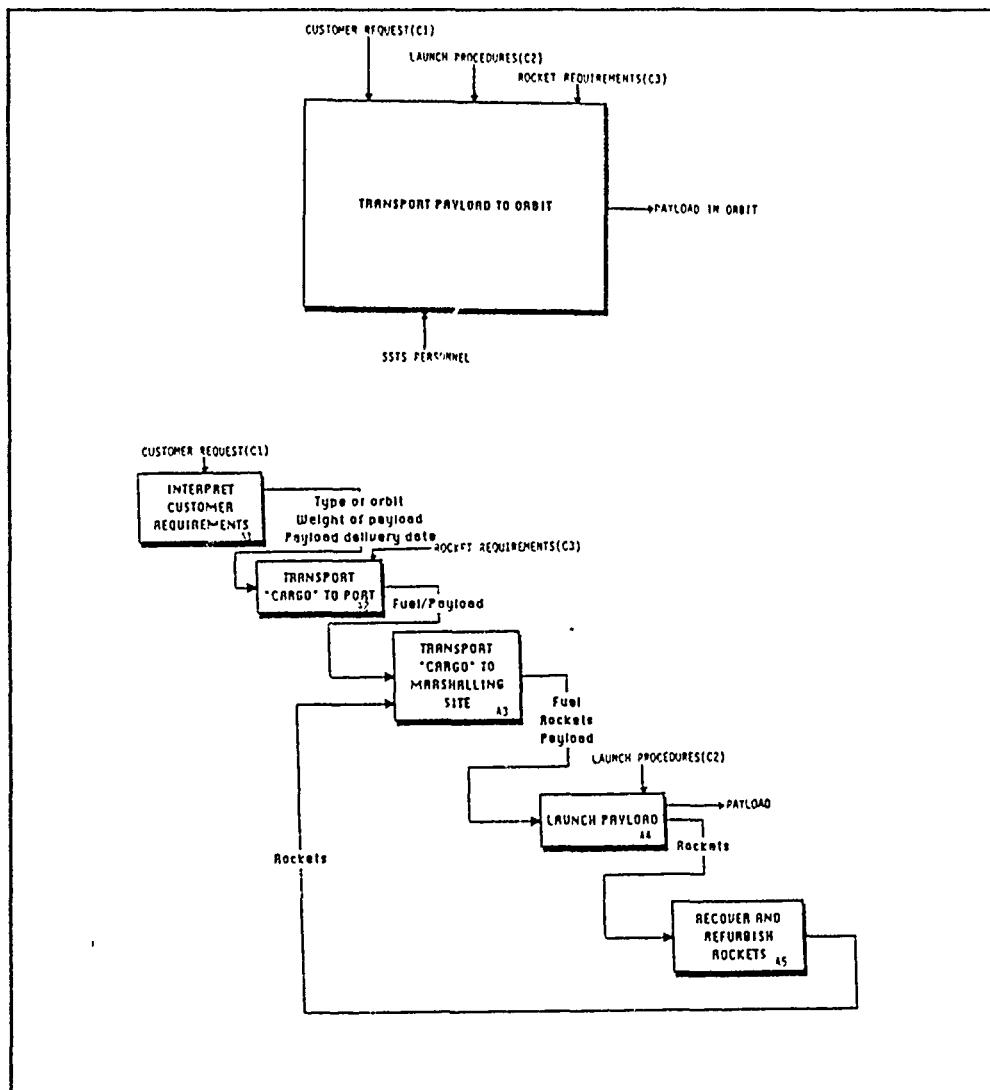
Figure 1: Transport Payload to Orbit

TABLE 1

EXAMPLE OF "CARGO" FOR LAUNCH OPERATIONS

```
                   CARGO FOR LAUNCH OPERATIONS
        Customer  Items
              Payload
              Special  Telemetry/Communications
              People
              Special  Fuels
              Checkout  Instrumentation
        Rocket  Subsystem  Items
              Fuels
              People
              Checkout  Equipment
              Tools
        Support  Subsystem  Items
              Fuel  Trucks
              Ballast  Equipment
              People
```

The customer's requests must be interpreted in order to develop a contract which specifies the weight of the payload to be delivered, the desired type of orbit and the desired payload delivery date. This contract will also have to specify the date on which the payload will be delivered to the port, as that will be the responsibility of the customer. These components of the A1 operation are depicted in Figure 2.

The contract established with the customer will be a major factor in determining what cargo is essential in accomplishing the mission. As shown in Figure 3, the engineers must determine the number and types of rockets required for the mission based on the weight of the payload and type of orbit desired, in addition to predetermined rocket requirements. The number and type of rockets will be the factors used in computing the amounts and types of fuels as well as the number of trucks required to transport the fuels to the port. The amount of fuel will be affected

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by the time delay between when the rockets are fueled and when they are launched, due to burn-off. The personnel required to assemble the rockets is also a function of the number and type of rockets. All of this cargo must be transported to the port (A2). The time of arrival to port of the cargo trucks will be dependent upon the speed of the trucks and the distance from the fuel production location to the port.
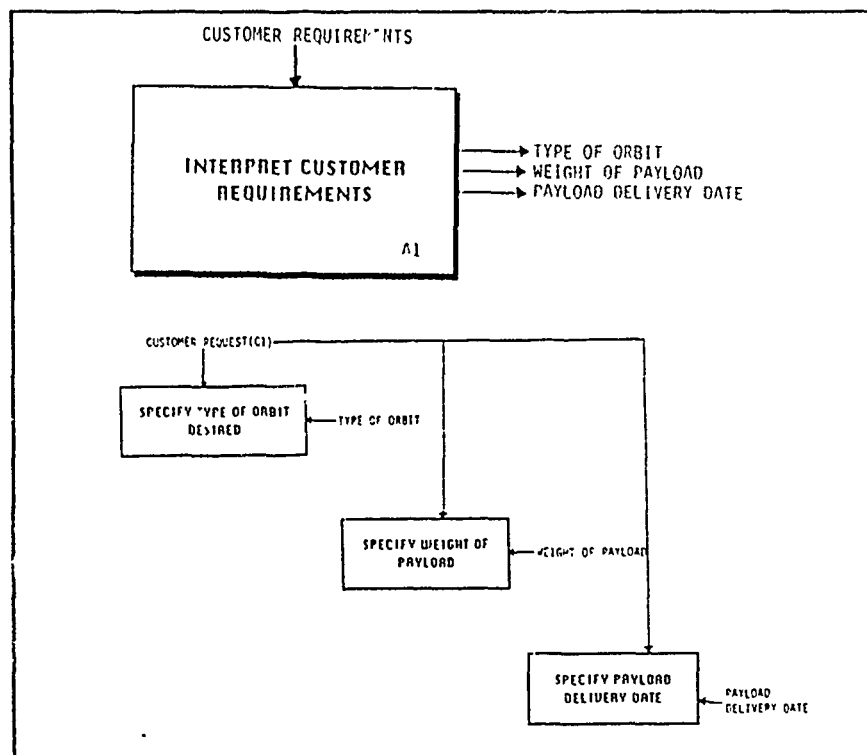
Figure 2: Interpret Customer Requirements (A1)
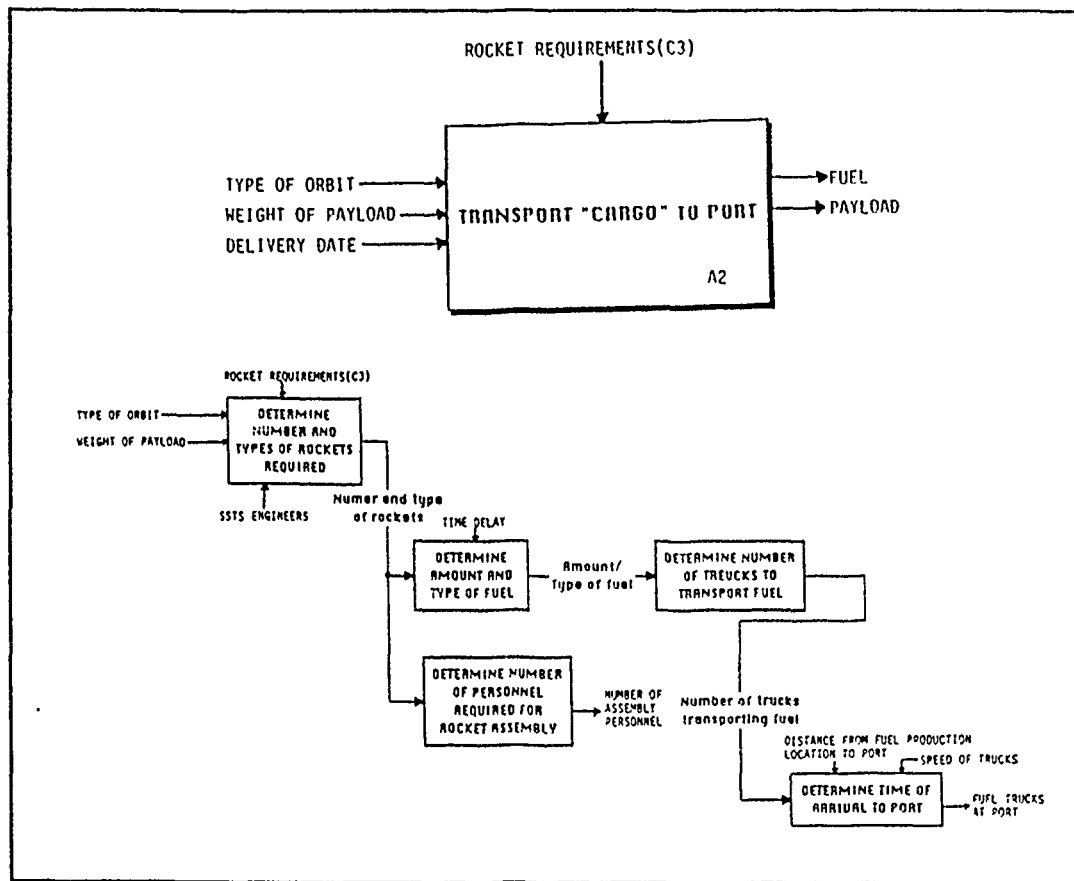
Figure 3: Transport "Cargo" to Port

In order to transport the fuel trucks, assembled rockets, payload and launch personnel to the launch site (A3), a determination must be made as to how many barges will be required (Figure 4). The arrival of the cargo to the marshalling site will be accomplished after the rockets have been assembled. The time of arrival will be based upon the speed of the barges as well as the distance from the port to the marshalling site.

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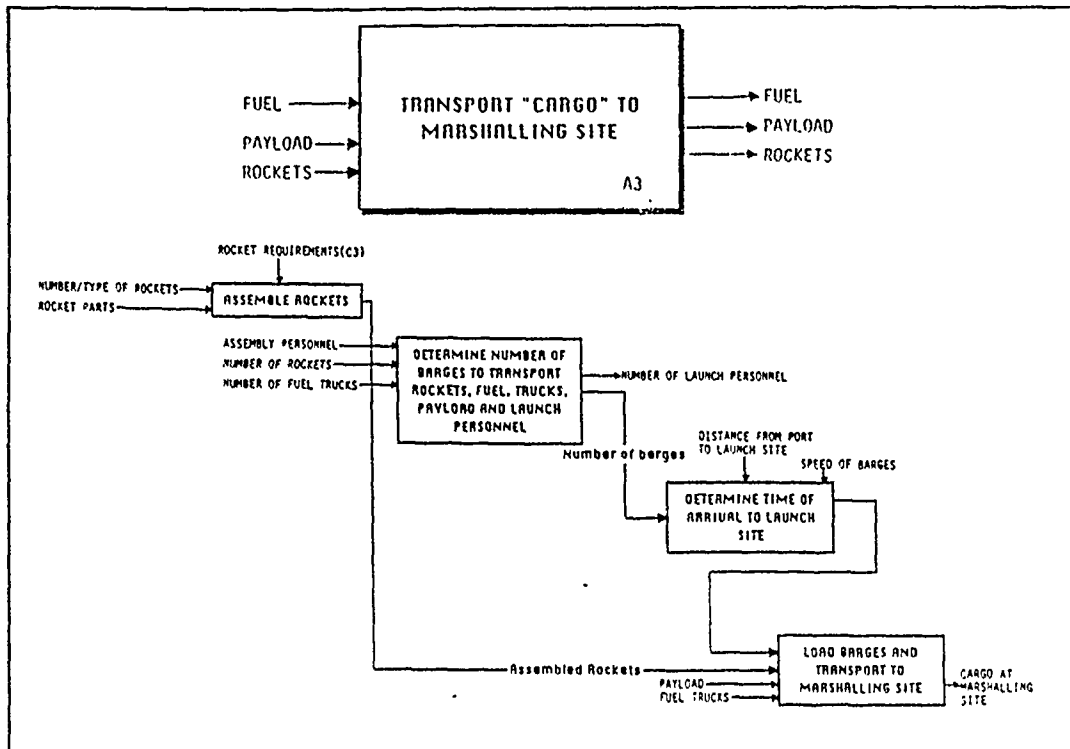
Figure 4: Transport "Cargo" to Marshalling Site (A3)

Once all of the cargo is in place at the marshalling site, the rockets are fueled. The payload/rocket assembly is then towed , the actual launch position and the payload is launched as indicated in Figure 5.

Although the actual mission of launching the payload has been accomplished, since these are recoverable rockets, they must be recovered and returned to port (Figure 6). Once they are returned, they must be refurbished and stored for subsequent launches.
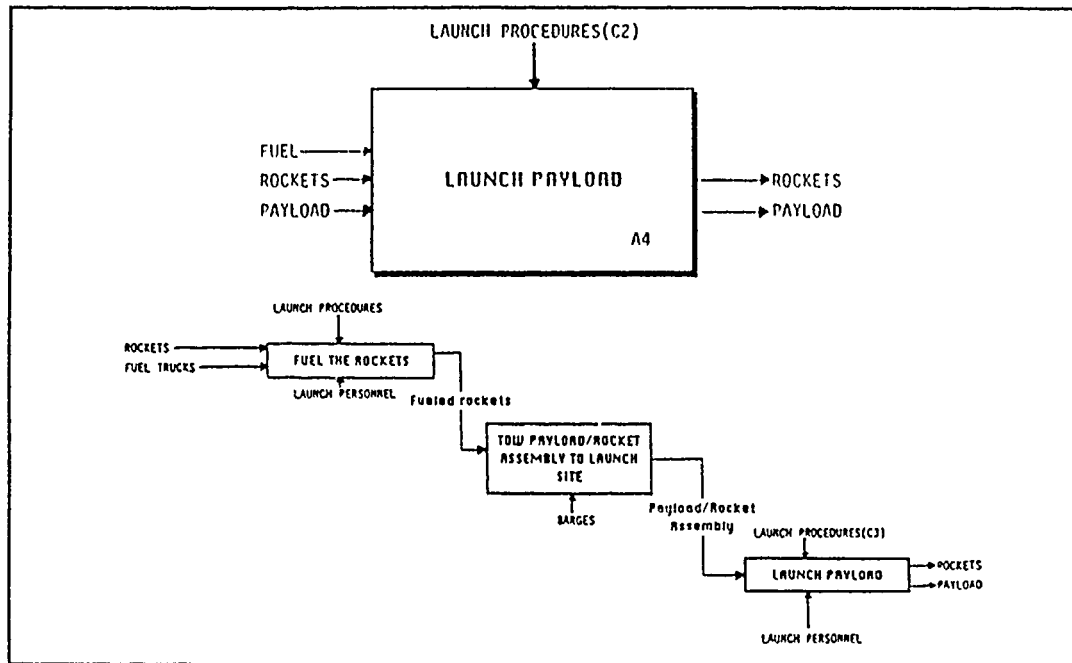
Figure 5: Launch Payload (A4)
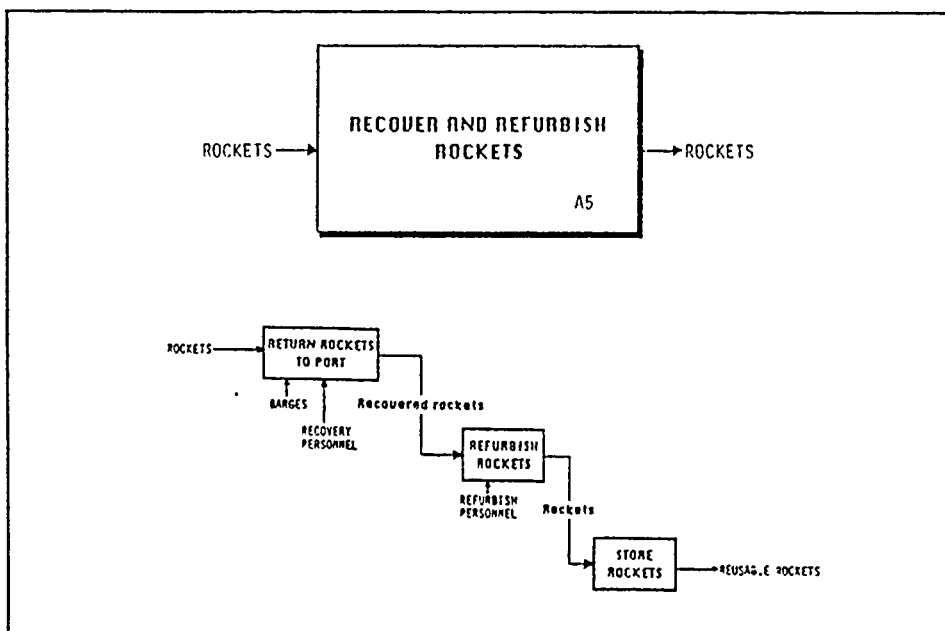
Figure 6: Recover and Refurbish Rockets (A5)

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IV. THE MODEL

An optimization model was developed for the Sea Launch and Recovery Transportation System. The objective of the cost estimation model was to minimize the cost per mission performed by the SSTS based on the concept of operations presented in the previous chapter. The model presented here by no means encompasses all of the cost components of the SSTS. This model merely minimizes the costs associated with the fuel tanks of the rocket. It can be used to aid the SSTS designers in making cost effective choices regarding the types of materials to be used in the construction of the fuel tanks. It can also be used in determining the most economical port of operation for the SSTS in terms of these fuel tank costs and the port operating costs.

GAMS (General Algebraic Modeling System) was chosen as the language to be utilized in this problem for several reasons, although this problem could be reduced to a rather simple computation. First, and foremost, GAMS is a high-level language that enables the compact representation of large models and it will be necessary to greatly expand this model to include/examine all of the various components associated with the SSTS. Secondly, although the problem as presented here is linear, it is envisioned that this problem structure may eventually change to include nonlinearities. For example, the research and development costs will most probably involve nonlinearities. GAMS is capable of solving both types of problems. Thirdly, the GAMS model representation is concise and can be easily understood.

A. OVERVIEW

This cost estimation model is used to investigate the economics of operating the Sea Launch and Recovery Space Transportation System from four ports: Honolulu, Hawaii; San Diego, California; Galveston, Texas; and Jacksonville, Florida. The fuels required for the operation of the SEALAR rockets include kerosene (RP-1), liquid oxygen (LOX), liquid hydrogen (LH2), and helium (HEL). In order for these fuels to be carried in the rocket, six fuel tanks are necessary: one RP-1, two LOX (one for each stage), one LH2 , and two HEL (one for each stage). Each of these tanks can be constructed from maraging steel, cryostretched stainless steel, or composites. Additionally, the RP-1, LH2 and HEL tanks can be constructed from titanium.

The Kellogg Company conducted an economic feasibility and optimization study to investigate the economics for producing, purchasing, transporting and storing three of the fuels required for the SSTS. It was based on providing the required quantities of those fuels to initially support twelve launches per year for the next five years (up to 1995) and seventy-two launches thereafter. This model is based on the same premise and makes use of the optimal fuel prices determined by that study. [Ref. 4]

The research and development costs of the tanks are calculated for the development of all of the possible combinations of tanks and materials. These costs are distributed over the total number of missions that the rocket is expected to perform while the cost of the tanks is distributed over the number of rocket reuses. The overhead costs, general expenses associated with the construction of the rocket, are distributed over the number of missions the rocket executes each year.

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The model provides reports which can be readily used to determine which port is the most economical in terms of cost per mission and cost per pound of payload based on the input data. A tabular display is also provided indicating the most cost efficient combination of tanks and materials. In addition, the individual costs for each of the major cost components (research and devlopment, operating, refurbishment and overhead) and the cost of the selected fuel tanks are offered in the reports. All of these reports are given based on twelve or seventy-two missions per year.

B. ALGEBRAIC REPRESENTATION

The optimization model of the SEALAR Space Transportaion System problem presented in Appendix A can be represented in algebraic terms as follows.

1. INDICES:

The data used in the model is indexed by fuel types, ports of operation, types of fuel tanks and types of materials used in the construction of fuel tanks. These indices are:

f   = types of fuels required for the SEALAR rocket (RP-1, LOX, LH2, HEL)

p   = ports of operation of the SSTS (Honolulu, HI; San Diego, CA; Galveston, TX; Jacksonville,FL)

t   = types of fuel tanks required for the SEALAR rocket (one RP-1, two LOX, one LH2, two HEL)

m   = types of materials used in the construction of fuel tanks (maraging steel, cryostretched stainless st -el, composites, titanium)

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2. GIVEN DATA:

The computation of the operating costs, one of the main costs of interest in this model, involved determining the cost of the fuels, the cost of transporting the cargo from the port to the launch site, and the cost of the SSTS personnel.

The data required to compute the cost of the fuels included:

a_f = amount of fuel type f required to launch a 10,000 lb payload (in kgs)

b_f = percent of the total capacity of fuel required to fill the tanks; the tanks are initially at room temperature and must be cooled to the cryogenic temperature of liquids (expressed as a decimal)

td_{fp} = additional fuel f required for "burn-off" while transiting from port p to the launch site (as % of total fuel requirement)

p_{fp} = price of fuel type f at port p (in $/kg) [Ref. 5]

The data necessary in determining the SSTS transportation costs were·

d_p = distance from port p to the launch site (in nautical miles)

s = speed of the transportation (barge, ship) from port to launch site (in miles/hr)

r = barge rental fee per day ($)

$nm1$ = nautical miles to retrieve stage one of the rocket

$nm2$ = nautical miles to retrieve stage two of the rocket

The personnel costs are determined by:

e = number of personnel

es = average annual salary and benefits of the personnel ($)

Minimizing the cost of the SEALAR rocket's fuel tanks was the other important factor in the model. It was necessary to determine the research and

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development costs, the unit production costs, the refurbishment costs, and the overhead costs since all of these are components of the total fuel tank costs.

That data which were associated with the research and development costs included:

c_m =   cost per pound of material m ($/lb)

dn_{mt} =   design cost for tank t constructed from material m ($)

pt_{mt} =   prototype and test costs for tank t constructed from material m ($)

pp_{mt} =   preproduction cost for tank t constructed from material m ($)

rd_{mt} =   amount of material m used in the research and development of tank t constructed of material m (in lbs)

The additional data required to compute the unit production costs are:

fab_{mt} =   fabrication cost of tank t constructed from material m ($)

mwt_{mt} =   weight of material m used to construct one tank of type t (in lbs)

u =   number of reuses of the fuel tanks

int_{mt} =   integration testing costs during production of tank t made of material m ($)

The recovery and refurbishment costs are determined by:

rec_{mt} =   cost to recover and wash off tank t constructed of material m ($)

i_{mt} =   time to inspect tank t constructed of material m (in hrs)

h_{mt} =   hourly rate to inspect tank t constructed of material m ($/hr)

rep_{mt} =   cost to repair tank t constructed of material m ($)

The overhead costs associated with the fuel tanks are designated as:

ov_{mt} =   overhead costs associated with tank t constructed of material m ($)

Other data that are necessary for the computation of the cost per mission and the cost per pound of payload delivered to orbit by the SSTS include:

num = number of Subcalibur rockets

mis = total number of missions

myr = number of missions per year

wt = payload weight (in lbs)

k_t = number of tanks of type t required per rocket

3. DERIVED DATA

In order to determine the port operating costs, the cost of fuels required for the rockets, the cost of transportation of the mated rockets and recovered stages, and the personnel costs are calculated according to the following equation:

$$\sum_r \left[\left(\left\{ \left[a_r + (a_r \times b_r) \right] + \left(\left\{ td_{rp} \times .01 \times \left[a_r + (a_r \times b_r) \right] \right\} \times \frac{wt}{10000} \right) \right\} \times p_{rp} \times num \right) + \left(\left\{ \left[(2 \times (d_p + nm1 + nm2)) \div s \right] \div 24 \right\} \times r \times num \right) + (e \times es) \right]$$

4. DECISION VARIABLE:

The model will determine the most cost efficient material to use in the construction of the required fuel tanks. This variable is defined as:

x_{mt} = number of tanks of type t constructed from material m

22

5. CONSTRAINTS:

The correct number of each type of tank must be constructed:

$$\sum_m x_{mt} = k_t \times num$$

Liquid oxygen tanks cannot be constructed from titanium so the following constraint was included in the model:

$$x_{mt} = 0 \text{ for } m=\text{Titanium and } t=\text{LOX}$$

There is also a nonnegativity constraint :

$$x_{mt} \geq 0$$

5. OBJECTIVE FUNCTION:

The objective of the optimization model is to minimize fuel tank costs:

Minimize TANKCOST = costs of tanks including research and development,

production, refurbishment and overhead costs

$$= \sum_m \sum_t \left[\begin{array}{l} \left\{ \left[dn_{mt} + pt_{mt} + pp_{mt} + (rd_{mt} \times c_m) \right] \div mis \right\} \\ + \left\{ \left(x_{mt} \times \left[(mwt_{mt} \times c_m) + fab_{mt} + in_{mt} \right] \right) \div u \right\} \\ + \left\{ x_{mt} \times \left[rec_{mt} + (i_{mt} \times h_{mt}) + rep_{mt} \right] \right\} + \left\{ (ov_{mt} \times x_{mt}) \div myr \right\} \end{array} \right]$$

The solution to this problem can be obtained by finding, for each tank t, the material m which has the lowest variable cost in the preceding equation. That is, for each t, select

$$\min_m \left[\begin{array}{l} \left\{ \left(\left[(mwt_{mt} \times c_m) + fab_{mt} + in_{mt} \right] \right) \div u \right\} \\ + \left\{ \left[rec_{mt} + (i_{mt} \times h_{mt}) + rep_{mt} \right] \right\} + \left\{ ov_{mt} \div myr \right\} \end{array} \right]$$

23

This solution can be obtained in closed form but the model has been implemented using an optimization solver to accomodate future extension.

V. ANALYSIS

The Sea Launch and Recovery Transportation System is in the development phase and, thus, there are no observed values with which to analyze the model presented in Chapter IV. It was therefore necessary to use estimates in analyzing the model and determining the relationships that exist between the variables. These estimates will be varied in the different scenarios to conduct sensitivity analysis.

A. SCENARIO NUMBER ONE

The estimates used in the optimization model of Appendix A generated the reports in Appendix B. Tables 2 and 3 summarize these reports. These tables present the operating costs for San Diego, California since it was determined to be the most economical port of operation.

TABLE 2

SSTS PER MISSION COSTS

(BASED ON 12 MISSIONS PER YEAR)

Number of Rocket Reuses	1	2	5	10	25
Research and Development	755,000	755,000	755,000	755,000	755,000
Tank Costs	4,945,000	2,473,000	989,000	495,000	198,000
Operating Costs	2,746,000	2,746,000	2,746,000	2,746,000	2,746,000
Refurbishment Costs	66,000	66,000	66,000	66,000	66,000
Overhead Costs	6,000	6,000	6,000	6,000	6,000
Cost Per Mission	8,518,000	6,045,000	4,561,000	4,067,000	3,770,000

TABLE 3

SSTS PER MISSION COSTS

(BASED ON 72 MISSIONS PER YEAR)

Number of Rocket Reuses	1	2	5	10	25
Research and Development	755,000	755,000	755,000	755,000	755,000
Tank Costs	4,945,000	2,473,000	989,000	495,000	198,000
Operating Costs	2,717,000	2,717,000	2,717,000	2,717,000	2,717,000
Refurbishment Costs	66,000	66,000	66,000	66,000	66,000
Overhead Costs	972	972	972	972	972
Cost Per Mission	8,484,000	6,011,000	4,528,000	4,033,000	3,736,000

In this base case, maraging steel was selected by the optimization program as the material from which all of the fuel tanks would be constructed regardless of the number of missions per year or the number of rocket reuses as shown in Table 4. The cost of these rocket fuel tanks accounts for the differences in the cost per mission as all other costs except the operating costs remain constant regardless of the number of missions per year or the number of reuses of the rocket as the tables indicate. The operating costs do, however, remain constant as the number of rocket reuses change because they are based on the number of rockets used in the mission. The constancy in the research and development costs is due to the fact that those costs are based on developing fuel tanks for all possible fuel-tank material combinations. Since the refurbishment and overhead costs are dependent upon the fuel-tank material combinations selected by the model and these combinations remained the same for all missions, these costs remain constant.

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TABLE 4

TANK COMBINATIONS SELECTED BASED ON THE NUMBER OF

ROCKET REUSES AND 12 OR 72 MISSIONS PER YEAR

TYPE OF FUEL TANK	1	2	5	10	25
KEROSENE	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
LIQUID OXYGEN (STAGE 1)	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
LIQUID OXYGEN (STAGE 2)	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
LIQUID HYDROGEN	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
HELIUM (STAGE 1)	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL
HELIUM (STAGE 2)	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL	MARAGING STEEL

The cost of the fuel tanks and thus the cost per mission decreases significantly as the number of reuses of the rocket increases. There is, in fact, a reduction of $4,748,000 when the fuel tanks are used twenty-five times instead of only once.

As expected, operating costs decreased as the number of missions per year increased (an approximate savings of $29,000). This is due to the fact that the fuel costs for liquid oxygen and liquid hydrogen decreased due to price breaks for bulk buying as the number of missions increased from twelve to seventy-two [Ref. 4]. Also, there is an inverse relationship between the number of missions per year and overhead costs. The overhead costs for 72 missions were one-sixth those for twelve missions. These reductions in operating and overhead costs resulted in a $34,000 per mission savings when conducting 72 missions rather than 12 missions per year.

27

However, regardless of the number of missions performed each year, the differences in per mission costs remain constant as the number of reuses increases.

B. SCENARIO NUMBER TWO

Since maraging steel was selected exclusively as the material for the fuel tanks in the first scenario, the cost per pound of maraging steel was increased to $30,000 (one hundred times its original cost) to verify that the model would select the most cost efficient combination of materials and fuel tanks. This price increase varied the selection of fuel-tank material combinations. The combinations of fuel tanks and materials that were selected are shown in Tables 5 and 6. It should be noted that in this scenario, the materials change as the number of reuses change but not with the change in the number of missions.per year.

TABLE 5

TANK COMBINATIONS SELECTED WHEN COST OF MARAGING

STEEL IS INCREASED SIGNIFICANTLY BASED 12 MISSIONS PER YEAR

TYPE OF FUEL TANK	1	2	5	10	25
KEROSENE	TITANIUM	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCH STEEL
LIQUID OXYGEN (STAGE 1)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID OXYGEN (STAGE 2)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID HYDROGEN	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
HELIUM (STAGE 1)	TITANIUM	TITANIUM	TITANIUM	TITANIUM	TITANIUM
HELIUM (STAGE 2)	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL

TABLE 6

TANK COMBINATIONS SELECTED BASED ON THE NUMBER OF

ROCKET REUSES AND 72 MISSIONS PER YEAR

TYPE OF FUEL TANK	1	2	5	10	25
KEROSENE	TITANIUM	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCHED STEEL
LIQUID OXYGEN (STAGE 1)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID OXYGEN (STAGE 2)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID HYDROGEN	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
HELIUM (STAGE 1)	TITANIUM	TITANIUM	TITANIUM	TITANIUM	TITANIUM
HELIUM (STAGE 2)	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL

As indicated in the reports for the second scenario found in Appendix C, tank, refurbishment, and overhead costs are dependent upon the type of material chosen for the tanks. Therefore, these costs vary if the type of tank material varies. A summary of the costs for this scenario for 12 missions, Table 7, indicates the operating costs and most economical port of operation were not affected by these choices. The costs for 72 missions per year were identical to those for twelve except for the reduction in operating and overhead costs. This verifies the results shown in the base case scenario (Scenario Number One).

TABLE 7

SSTS PER MISSION COSTS

(BASED ON 12 MISSIONS PER YEAR WHEN THE COST OF

MARAGING STEEL IS INCREASED SIGNIFICANTLY)

Number of Rocket Reuses	1	2	5	10	25
Research and Development	11,748,000	11,748,000	11,748,000	11,748,000	11,748,000
Tank Costs	6,737,000	3,375,000	1,350,000	676,000	273,000
Operating Costs	2,746,000	2,746,000	2,746,000	2,746,000	2,746,000
Refurbishment Costs	83,000	72,000	72,000	71,000	66,000
Overhead Costs	2,667	2,667	2,667	2,792	2,792
Cost Per Mission	21,316,667	17,943,667	15,918,667	15,243,792	14,835,792

C. SCENARIO NUMBER THREE

As a third scenario, the cost of composites were decreased to $200 per pound while the cost of maraging steel remained at $30,000 per pound. The reports generated by this scenario are in Appendix D. Table 8 displays the choices made for the fuel-tank material combinations. As in the previous case, the choices remained the same regardless of the number of missions per year. This scenario further verified that the most economical combination of fuel tanks and materials would be chosen by the model and that San Diego is the most economical port of operation.

TABLE 8

TANK COMBINATIONS SELECTED BASED ON THE NUMBER OF
ROCKET REUSES

TYPE OF FUEL TANK	1	2	5	10	25
KEROSENE	TITANIUM	TITANIUM	TITANIUM	TITANIUM	CRYOSTRETCHE D STEEL
LIQUID OXYGEN (STAGE 1)	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES
LIQUID OXYGEN (STAGE 2)	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
LIQUID HYDROGEN	TITANIUM	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL	CRYOSTRETCH STAINLESS STEEL
HELIUM (STAGE 1)	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES
HELIUM (STAGE 2)	COMPOSITES	COMPOSITES	COMPOSITES	COMPOSITES	CRYOSTRETCH STAINLESS STEEL

D. SCENARIO NUMBER FOUR

The research and development costs in all of the previous scenarios were based on developing all of the possible fuel-tank material combinations. In trying to further reduce the cost per mission, a variation of the model was implemented in which research and development costs would be calculated for only those fuel tank-material combinations selected by the model. This variation involved changing the objective function of the model to include the decision variable in the calculation of the research and development costs. The new objective function is:

31

Minimize TANKCOST

$$
= \sum_m \sum_t \left[\begin{array}{l} \left\{ \left[\left(dn_{mt} + pt_{mt} + pp_{mt} + \left(rd_{mt} \times c_m \right) \right] \times H_{mt} \right) \div mis \right\} \\ + \left\{ \left(H_{mt} \times \left[\left(mwt_{mt} \times c_m \right) + fab_{mt} + in_{mt} \right] \right) \div u \right\} \\ + \left\{ H_{mt} \times \left[rec_{mt} + \left(i_{mt} \times h_{mt} \right) + rep_{mt} \right] \right\} + \left\{ \left(ov_{mt} \times H_{mt} \right) \div myr \right\} \end{array} \right]
$$

The reports generated using this objective function for the three scenarios are contained in Appendix E. It was found that the research and development costs were significantly reduced but that all other costs remained the same. The savings for the three different scenarios is shown in Table 9. Once again, it is evident that the savings is dependent upon the type of material chosen for the rocket fuel tanks.

TABLE 9

SAVINGS FROM CALCULATING RESEARCH AND DEVELOPMENT

COSTS FOR SPECIFIED TANKS ONLY

SCENARIO	SAVINGS
NUMBER ONE	755,000 - 130,000 = 625,000
NUMBER TWO	11,748,000 - 178,000 = 11,570,000
NUMBER THREE	11,449,000 - 86,000 = 11,363,000

The possible variations in this model are endless considering that only estimates are being utilized in the analysis. It has been verified, however, that the operating costs of the Sea Launch and Recovery Space Transportation System can be reduced significantly if the number of reuses of the rocket can be increased. Furthermore,

32

the cost of the rocket fuel tanks is dependent upon the variation of the materials used in their construction but can be reduced significantly if research and development is conducted only for the most cost efficient tanks selected for the mission.

VI. CONCLUSIONS

This study indicates that it is possible to develop a cost estimation model for the rocket fuel tanks and operating costs associated with the Sea Launch and Recovery Space Transportation System. The cost of the material used in the fuel tanks can have a significant effect on the cost per mission of the SSTS. A signicant decrease in costs can also be achieved by developing only those fuel-tank material combinations selected by the model.

It is recommended that as actual data becomes available, additional studies be conducted in order to verify and correct, as necessary, those assumptions and simplifications used in this model. In addition, this model should eventually be expanded to include every possible component of the SSTS. It is only through the development of such a model that the true economic value of the SSTS can be determined.

LIST OF REFERENCES

1. Truax Engineering, Inc., "Proposal for SEALAR Program", 1988.

2. Truax, R. C., "Sea Dragon in the Manned Mars Mission", paper, 1987.

3. *Aerojet General Report LRP 297*, February 1963.

4. Naval Research Laboratory, Memorandum Report 3086, "Structured Analysis Model for Naval Telecommunications Procedures User's Manual NTP3", July 1975.

5. M. W. Kellogg Company, "Cyrogenics Study", paper presented to the Naval Research Laboratory, 1990.

APPENDIX A

SEALAR SPACE TRANSPORTATION SYSTEM MODEL

```
 3   OPTION LIMROW=0, LIMCOL=0 ;
 4
 5
 6   * By: LAYNE R. BOONE (7 AUG 90)
 7
 8
 9   ***********************************************************************
10   *      THIS IS THE BEGINNING OF THE INPUT DATA FOR THE SSTS
11   ***********************************************************************
12
13
14   SETS
15         F   fuel types         / KEROSENE, OXYGEN, HYDROGEN, HELIUM /
16         P   ports              / HONOLULU, SANDIEGO, GALVESTON, JACKSONVIL/
17         M   types of tank materials / MARAGING, CRYOSTRCH, COMPOSITES,
18                                         TITANIUM /
19         T   tank types         / RP1, LOX1, LOX2, LH2, HEL1, HEL2/ ;
20
21   SCALARS  NUM       number of Subcalibur rockets / 1 /
22            NUMMIS    total number of missions  / 100 /
23            MISYR     missions per year  / 12 /
24            WT        payload weight   / 10000 / ;
25
26   PARAMETER AMT(F)   amount of fuel type f required for 10000 lb payload
27
28                    / KEROSENE    1079
29                      OXYGEN     150152
30                      HYDROGEN    9815
31                      HELIUM      591 / ;
32
33   PARAMETER BOFF(F) boil-off allowances for fuel type f
34
35                    / KEROSENE   0.0
36                      OXYGEN     .30
37                      HYDROGEN   1.00
38                      HELIUM     2.80 / ;
39
40   TABLE   TDREQ(F,P)  additional fluid requirements for time delay
41
42                       HONOLULU  SANDIEGO  GALVESTON   JACKSONVIL
43          KEROSENE       0.0       0.0       0.0         0.0
44          OXYGEN         3.0       4.5       9.0         6.75
45          HYDROGEN       2.0       3.0       6.0         4.5
46          HELIUM         6.0       9.0      18.0        12.0        ;
47
48   TABLE   PRICE(F,P)  best price per kg of fuel f at port p
49
50                       HONOLULU  SANDIEGO  GALVESTON   JACKSONVIL
51          KEROSENE       0.14      0.14      0.14        0.14
52          OXYGEN         0.51      0.18      0.18        0.18
53          HYDROGEN      11.11      5.93      4.52        4.74
54          HELIUM        22.03     10.13      9.91       10.26        ;
55
56
57   PARAMETER DIST(P)  distance from port p to launch site in miles
58
```

36

```
59                       / HONOLULU      1560
60                         SANDIEGO      2380
61                         GALVESTON     4630
62                         JACKSONVIL    3690 /  ;
63
64
65   SCALAR BSPEED   average barge speed  / 17 / ;
66
67   SCALAR BRENT   barge rental fee per day / 5000 / ;
68
69   SCALAR NMTO1 miles to retrieve first stage / 200 / ;
70
71   SCALAR NMTO2 miles to retrieve second stage / 50 / ;
72
73   SCALAR PERS number of personnel / 50 / ;
74
75   SCALAR SALARY average annual salary / 50000 / ;
76
77   PARAMETER TANK(T) number of tanks of type t required per rocket
78
79                       / RP1        1
80                         LOX1       1
81                         LOX2       1
82                         LH2        1
83                         HEL1       1
84                         HEL2       1 / ;
85
86   PARAMETER MCOST(M) cost per pound of material type m
87
88                       / MARAGING        300
89                         CRYOSTRCH       500
90                         COMPOSITES      3000
91                         TITANIUM        700 / ;
92
93   TABLE FABRICATE(M,T) fabrication cost of tank t of material m
94
95                        RP1       LOX1      LOX2      LH2       HEL1      HEL2
96      MARAGING         100000    300000    250000    400000    50000     40000
97      CRYOSTRCH        100000    400000    350000    500000    60000     50000
98      COMPOSITES       1000000   1200000   1100000   1000000   100000    90000
99      TITANIUM         110000    0         0         500000    60000     50000 ;
100
101  TABLE DESIGN(M,T) design cost for tank t of material type m
102
103                       RP1       LOX1      LOX2      LH2       HEL1      HEL2
104     MARAGING         50000     70000     70000     120000    40000     70000
105     CRYOSTRCH        50000     70000     70000     120000    40000     70000
106     COMPOSITES       100000    140000    140000    240000    80000     60000
107     TITANIUM         50000     0         0         100000    40000     30000 ;
108
109  TABLE TEST(M,T) prototype and test cost for tank of material type m
110
111                       RP1       LOX1      LOX2      LH2       HEL1      HEL2
112     MARAGING         200000    220000    200000    250000    50000     40000
113     CRYOSTRCH        300000    250000    250000    300000    50000     50000
114     COMPOSITES       600000    700000    700000    850000    60000     50000
```

```
115        TITANIUM       300000      0         0        450000    50000    40000 ;
116
```

117 TABLE PREPRO(M,T) preproduction cost for tank t of material type m
118

119		RP1	LOX1	LOX2	LH2	HEL1	HEL2
120	MARAGING	100000	100000	100000	150000	40000	30000
121	CRYOSTRCH	100000	125000	125000	175000	50000	40000
122	COMPOSITES	250000	200000	200000	300000	60000	50000
123	TITANIUM	150000	0	0	250000	40000	30000 ;

124

125 TABLE RDAMT(M,T) amount of material type m used in r and d of tank t
126

127		RP1	LOX1	LOX2	LH2	HEL1	HEL2
128	MARAGING	7134	17343	1953	2676	7221	687
129	CRYOSTRCH	6141	14928	1680	2304	6216	591
130	COMPOSITES	1986	4830	543	744	2010	192
131	TITANIUM	4065	0	0	1524	4113	390 ;

132

133 TABLE MMT(M,T) weight of material type m used in one tank
134

135		RP1	LOX1	LOX2	LH2	HEL1	HEL2
136	MARAGING	2378	5781	651	892	2407	229
137	CRYOSTRCH	2047	4976	560	768	2072	197
138	COMPOSITES	662	1610	181	248	670	64
139	TITANIUM	1355	0	0	508	1371	130 ;

140

141 TABLE RECOVERY(M,T) recovery and wash off cost for type m of tank t
142

143		RP1	LOX1	LOX2	LH2	HEL1	HEL2
144	MARAGING	10000	12000	12000	20000	2000	2000
145	CRYOSTRCH	10000	12000	12000	20000	2000	2000
146	COMPOSITES	20000	24000	24000	40000	4000	4000
147	TITANIUM	15000	0	0	30000	3000	3000 ;

148

149 TABLE INSPECT(M,T) inspection time for tank t of material type m
150

151		RP1	LOX1	LOX2	LH2	HEL1	HEL2
152	MARAGING	5	8	8	12	1	1
153	CRYOSTRCH	1	2	2	3	.5	.5
154	COMPOSITES	6	9	9	15	2	2
155	TITANIUM	1	0	0	3	.5	.5 ;

156

157 PARAMETER RATE(M) rate per hour for inspection of type m material
158

```
159        / MARAGING        60
160          CRYOSTRCH       70
161          COMPOSITES     200
162          TITANIUM        60  / ;
163
```

164 TABLE REPAIR(M,T) repair cost for tank t of material type m
165

166		RP1	LOX1	LOX2	LH2	HEL1	HEL2
167	MARAGING	1000	1200	1200	2000	200	200
168	CRYOSTRCH	1000	1200	1200	2000	200	200
169	COMPOSITES	2000	2400	2400	4000	400	400
170	TITANIUM	1500	0	0	3000	300	300 ;

```
171
172  SCALAR REUSE number of reuses of tanks / 1 / ;
173
174  TABLE UTEST(M,T) unit test cost for tank t of material type m
175
176                       RP1       LOX1      LOX2      LH2       HEL1      HEL2
177      MARAGING         20000     20000     20000     30000     8000      6000
178      CRYOSTRCH        20000     25000     25000     35000     10000     8000
179      COMPOSITES       50000     40000     40000     60000     12000     10000
180      TITANIUM         30000     0         0         50000     8000      6000 ;
181
182  TABLE OVHEAD(M,T) overhead cost for tank t of material type m
183
184                       RP1       LOX1      LOX2      LH2       HEL1      HEL2
185      MARAGING         20000     10000     10000     20000     5000      5000
186      CRYOSTRCH        10000     5000      5000      10000     2500      2500
187      COMPOSITES       60000     30000     30000     60000     15000     15000
188      TITANIUM         10000     0         0         10000     1000      1000 ;
189
190
191  *****************************************************************************
192  *      THIS IS THE BEGINNING OF THE CALCULATIONS REQUIRED TO COMPUTE
193  *      THE COST PER MISSION FOR THE PORT OPERATIONS AND THE ROCKET
194  *      FUEL TANKS
195  *****************************************************************************
196
197
198  PARAMETERS
199      ADD(F)          additional fuel required to account for boiloff
200      NEWAMT(F)       required fuel plus additional fuel
201      FREQ(F,P)       total amount of fuel required for payload of weight wt
202      FUELCOST(P)     cost of fuel for payload of weight wt
203      TRANSCOST(P)    cost of transportation
204      PERSCOST        personnel costs
205      OPCOST(P)       total operating costs at port p
206      RDCOST(M,T)     research and development cost for tank t of material m
207      RD              research and development cost per mission for tanks
208      UNITCOST(M,T)   unit production cost for tank t of material m
209      REFURB(M,T)     refurbishment cost for tank t of material m   ;
210
211  *****************************************************************************
212  *      THESE ARE THE CALCULATIONS FOR THE OPERATING COSTS
213  *****************************************************************************
214
215
216  ADD(F) = AMT(F) * BOFF(F) ;
217
218  NEWAMT(F) = ADD(F) + AMT(F)  ;
219
220  FREQ(F,P) = (NEWAMT(F) + (TDREQ(F,P) * .01 * NEWAMT(F))) * (WT/10000) ;
221
222  FUELCOST(P) = SUM(F, FREQ(F,P) * PRICE(F,P)) * NUM;
223
224  TRANSCOST(P) =
225          (((2 * (DIST(P) + NMTO1 + NMTO2))/BSPEED)/24) * BRENT * NUM ;
226
```

```
227   PERSCOST = PERS * SALARY ;
228
229   OPCOST(P) =  (FUELCOST(P) + TRANSCOST(P) + PERSCOST) ;
230
231
232   ********************************************************************
233   *      THESE CALCULATIONS ARE REQUIRED FOR THE FUEL TANK COSTS
234   ********************************************************************
235
236   RDCOST(M,T) = DESIGN(M,T)+TEST(M,T)+PREPRO(M,T)+(RDAMT(M,T)*MCOST(M)) ;
237
238   RD = (SUM((M,T), RDCOST(M,T))/NUMMIS);
239
240   UNITCOST(M,T) = (MMT(M,T) * MCOST(M)) + FABRICATE(M,T) + UTEST(M,T) ;
241
242   REFURB(M,T) = (RECOVERY(M,T) + (INSPECT(M,T)*RATE(M)) + REPAIR(M,T)) ;
243
244   VARIABLES
245      X(M,T)          number of tanks type t of material m
246      TANKS           cost of tanks for this mission
247      REF             total recovery and refurbishment costs for this mission
248      OVH             total overhead costs for tanks per mission per year
249      TOTCOST         total cost of tanks ;
250
251   POSITIVE VARIABLES X, TANKS, REF, OVH;
252
253   EQUATIONS
254      REQTANKS(T)     number of tanks of type t required for the mission
255      TCOST           cost of tanks for this mission
256      REFURBISH       total recovery and refurbishment costs for this mission
257      OVERHEAD        total overhead costs for tanks per mission per year
258      TANKCOST        total cost of tanks ;
259
260
261   ********************************************************************
262   *      THESE CALCULATIONS ARE ALSO REQUIRED FOR THE FUEL TANK COSTS
263   ********************************************************************
264
265
266   REQTANKS(T)..    SUM(M, X(M,T)) =E= (TANK(T) * NUM) ;
267
268   TCOST..          TANKS =E=
269                        SUM((M,T), (X(M,T) * UNITCOST(M,T))/REUSE );
270
271   REFURBISH..      REF =E= SUM((M,T), X(M,T) * REFURB(M,T)) ;
272
273   OVERHEAD..       OVH =E= (SUM((M,T), (OVHEAD(M,T)*X(M,T)))/MISYR) ;
274
275
276   ********************************************************************
277   *      THIS CALCULATION IS REQUIRED FOR PORT COST PER MISSION
278   ********************************************************************
279
280
281   TANKCOST..    TOTCOST =E= RD + TANKS + REF + OVH ;
282
```

40

```
283   MODEL SSTS /ALL/ ;
284
285
286   ****************************************************************
287   *     THIS IS WHERE THE FORMATING FOR THE REPORTS BEGINS.
288   *     THE REPORTS ARE FORMULATED SO ONE CAN EASILY DETERMINE WHICH
289   *     PORT IS MOST ECONOMICAL AND WHICH TYPE TANKS ARE MOST COST
290   *     EFFICIENT.
291   ****************************************************************
292
293
294   PARAMETER REPORT1(*,*)  port costs per mission for 12 missions per year ;
295   PARAMETER REPORT7(*,*)  port costs per lb for twelve missions per year ;
296   PARAMETER REPORT2(*,*,*)  number of tanks for 12 missions per year ;
297   PARAMETER REPORT3(*,*)  port costs per mission for 72 missions per year ;
298   PARAMETER REPORT8(*,*)  port costs per lb for 72 missions per year ;
299   PARAMETER REPORT4(*,*,*)  number of tanks for 72 missions per year ;
300   PARAMETER REPORT5(*) research and development costs per mission ;
301   PARAMETER REPORT6(*) research and development costs per mission ;
302   PARAMETER REPORT9(*)  refurbishment costs per mission ;
303   PARAMETER REPORT11(*)  refurbishment costs per mission ;
304   PARAMETER REPORT10(*)  overhead costs per mission ;
305   PARAMETER REPORT12(*)  overhead costs per mission ;
306   PARAMETER REPORT13(*)  tank costs per mission ;
307   PARAMETER REPORT14(*)  tank costs per mission ;
308   PARAMETER REPORT15(*,*)  operating costs at port p for this mission ;
309   PARAMETER REPORT16(*,*)  operating costs at port p for this mission ;
310
311
312   ****************************************************************
313   *     THE FOLLOWING TWO LINES ENSURE THAT TITANIUM IS NOT USED
314   *     FOR THE LOX1 OR LOX2 TANKS (THIS IS A RESTRICTION)
315   ****************************************************************
316
317
318   X.FX("TITANIUM","LOX1") = 0;
319   X.FX("TITANIUM","LOX2") = 0 ;
320
321
322   ****************************************************************
323   *     THE REPORTS FOR 12 MISSIONS PER YEAR BEGIN HERE
324   *     THE NUMBER OF ROCKET REUSES ARE 1, 2, 5, 10, AND 25
325   ****************************************************************
326
327
328   REUSE = 1;
329   SOLVE SSTS USING LP MINIMIZING TOTCOST      ;
330   REPORT5('one reuse') = RD;
331   REPORT2(M,T,'one') = X.L(M,T);
332   REPORT13('one reuse') = TANKS.L;
333   REPORT15(P,'one reuse') = OPCOST(P);
334   REPORT9('one reuse') = REF.L;
335   REPORT10('one reuse') = OVH.L;
336   REPORT1(P,'one reuse') = OPCOST(P) + TOTCOST.L ;
337   REPORT7(P,'one reuse') = (OPCOST(P) + TOTCOST.L)/WT;
338
```

```
339  REUSE = 2;
340  SOLVE SSTS USING LP MINIMIZING TOTCOST      ;
341  REPORT5('two reuses') = RD;
342  REPORT2(M,T,'two reuses') = X.L(M,T);
343  REPORT13('two reuses') = TANKS.L;
344  REPORT15(P,'two reuses') = OPCOST(P);
345  REPORT9('two reuses') = REF.L;
346  REPORT10('two reuses') = OVH.L;
347  REPORT1(P,'two reuses') = OPCOST(P) + TOTCOST.L ;
348  REPORT7(P,'two reuses') = (OPCOST(P) + TOTCOST.L)/WT;
349
350  REUSE = 5;
351  SOLVE SSTS USING LP MINIMIZING TOTCOST      ;
352  REPORT5('five reuse') = RD;
353  REPORT2(M,T,'five reuse') = X.L(M,T);
354  REPORT13('five reuse') = TANKS.L;
355  REPORT15(P,'five reuse') = OPCOST(P);
356  REPORT9('five reuse') = REF.L;
357  REPORT10('five reuse') = OVH.L;
358  REPORT1(P,'five reuse') = OPCOST(P) + TOTCOST.L ;
359  REPORT7(P,'five reuse') = (OPCOST(P) + TOTCOST.L)/WT;
360
361  REUSE = 10;
362  SOLVE SSTS USING LP MINIMIZING TOTCOST      ;
363  REPORT5('ten reuses') = RD;
364  REPORT2(M,T,'ten reuses') = X.L(M,T);
365  REPORT13('ten reuses') = TANKS.L;
366  REPORT15(P,'ten reuses') = OPCOST(P);
367  REPORT9('ten reuses') = REF.L;
368  REPORT10('ten reuses') = OVH.L;
369  REPORT1(P,'ten reuses') = OPCOST(P) + TOTCOST.L ;
370  REPORT7(P,'ten reuses') = (OPCOST(P) + TOTCOST.L)/WT;
371
372  REUSE = 25;
373  SOLVE SSTS USING LP MINIMIZING TOTCOST      ;
374  REPORT5('25 reuses') = RD;
375  REPORT2(M,T,'25 reuses') = X.L(M,T);
376  REPORT13('25 reuses') = TANKS.L;
377  REPORT15(P,'25 reuses') = OPCOST(P);
378  REPORT9('25 reuses') = REF.L;
379  REPORT10('25 reuses') = OVH.L;
380  REPORT1(P,'25 reuses') = OPCOST(P) + TOTCOST.L ;
381  REPORT7(P,'25 reuse') = (OPCOST(P) + TOTCOST.L)/WT;
382
383
384  ****************************************************************
385  *      THE REPORTS FOR 72 MISSIONS PER YEAR BEGIN HERE
386  *      THE FUEL PRICES CHANGE FOR OXYGEN AND HYDROGEN
387  *      THE NUMBER OF ROCKET REUSES ARE 1, 2, 5, 10, AND 25
388  ****************************************************************
389
390
391  PRICE("OXYGEN","HONOLULU")=0.31;
392  PRICE("OXYGEN","SANDIEGO")=0.13;
393  PRICE("OXYGEN","GALVESTON")=0.13;
394  PRICE("OXYGEN","JACKSONVIL")=0.13;
```

```
395  PRICE("HYDROGEN","HONOLULU")=6.59;
396  PRICE("HYDROGEN","SANDIEGO")=5.00;
397  PRICE("HYDROGEN","GALVESTON")=3.88;
398  PRICE("HYDROGEN","JACKSONVIL")=4.10;
399  MISYR = 72 ;
400  REUSE = 1;
401  SOLVE SSTS USING LP MINIMIZING TOTCOST      ;
402  REPORT6('one reuse') = RD;
403  REPORT4(M,T,'one') = X.L(M,T);
404  REPORT14('one reuse') = TANKS.L;
405  REPORT16(P,'one reuse') = OPCOST(P);
406  REPORT11('one reuse') = REF.L;
407  REPORT12('one reuse') = OVH.L;
408  REPORT3(P,'one reuse') = OPCOST(P) + TOTCOST.L ;
409  REPORT8(P,'one reuse') = (OPCOST(P) + TOTCOST.L)/MT;
410
411  PRICE("OXYGEN","HONOLULU")=0.31;
412  PRICE("OXYGEN","SANDIEGO")=0.13;
413  PRICE("OXYGEN","GALVESTON")=0.13;
414  PRICE("OXYGEN","JACKSONVIL")=0.13;
415  PRICE("HYDROGEN","HONOLULU")=6.59;
416  PRICE("HYDROGEN","SANDIEGO")=5.00;
417  PRICE("HYDROGEN","GALVESTON")=3.88;
418  PRICE("HYDROGEN","JACKSONVIL")=4.10;
419  MISYR = 72 ;
420  REUSE = 2;
421  SOLVE SSTS USING LP MINIMIZING TOTCOST      ;
422  REPORT6('two reuses') = RD;
423  REPORT4(M,T,'two reuses') = X.L(M,T);
424  REPORT14('two reuses') = TANKS.L;
425  REPORT16(P,'two reuses') = OPCOST(P);
426  REPORT11('two reuses') = REF.L;
427  REPORT12('two reuses') = OVH.L;
428  REPORT3(P,'two reuses') = OPCOST(P) + TOTCOST.L ;
429  REPORT8(P,'two reuses') = (OPCOST(P) + TOTCOST.L)/MT;
430
431  PRICE("OXYGEN","HONOLULU")=0.31;
432  PRICE("OXYGEN","SANDIEGO")=0.13;
433  PRICE("OXYGEN","GALVESTON")=0.13;
434  PRICE("OXYGEN","JACKSONVIL")=0.13;
435  PRICE("HYDROGEN","HONOLULU")=6.59;
436  PRICE("HYDROGEN","SANDIEGO")=5.00;
437  PRICE("HYDROGEN","GALVESTON")=3.88;
438  PRICE("HYDROGEN","JACKSONVIL")=4.10;
439  MISYR = 72 ;
440  REUSE = 5;
441  SOLVE SSTS USING LP MINIMIZING TOTCOST      ;
442  REPORT6('five reuse') = RD;
443  REPORT4(M,T,'five reuse') = X.L(M,T);
444  REPORT14('five reuse') = TANKS.L;
445  REPORT16(P,'five reuse') = OPCOST(P);
446  REPORT11('five reuse') = REF.L;
447  REPORT12('five reuse') = OVH.L;
448  REPORT3(P,'five reuse') = OPCOST(P) + TOTCOST.L ;
449  REPORT8(P,'five reuse') = (OPCOST(P) + TOTCOST.L)/MT;
450
```

```
451   PRICE("OXYGEN","HONOLULU")=0.31;
452   PRICE("OXYGEN","SANDIEGO")=0.13;
453   PRICE("OXYGEN","GALVESTON")=0.13;
454   PRICE("OXYGEN","JACKSONVIL")=0.13;
455   PRICE("HYDROGEN","HONOLULU")=6.59;
456   PRICE("HYDROGEN","SANDIEGO")=5.00;
457   PRICE("HYDROGEN","GALVESTON")=3.88;
458   PRICE("HYDROGEN","JACKSONVIL")=4.10;
459   MISYR = 72 ;
460   REUSE = 10;
461   SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
462   REPORT6('ten reuses') = RD;
463   REPORT4(M,T,'ten reuses') = X.L(M,T);
464   REPORT14('ten reuses') = TANKS.L;
465   REPORT16(P,'ten reuses') = OPCOST(P);
466   REPORT11('ten reuses') = REF.L;
467   REPORT12('ten reuses') = OVH.L;
468   REPORT3(P,'ten reuses') = OPCOST(P) + TOTCOST.L ;
469   REPORT8(P,'ten reuses') = (OPCOST(P) + TOTCOST.L)/WT;
470
471   PRICE("OXYGEN","HONOLULU")=0.31;
472   PRICE("OXYGEN","SANDIEGO")=0.13;
.473   PRICE("OXYGEN","GALVESTON")=0.13;
474   PRICE("OXYGEN","JACKSONVIL")=0.13;
475   PRICE("HYDROGEN","HONOLULU")=6.59;
476   PRICE("HYDROGEN","SANDIEGO")=5.00;
477   PRICE("HYDROGEN","GALVESTON")=3.88;
478   PRICE("HYDROGEN","JACKSONVIL")=4.10;
479   MISYR = 72 ;
480   REUSE = 25;
481   SOLVE SSTS USING LP MINIMIZING TOTCOST    ;
482   REPORT6('25 reuses') = RD;
483   REPORT4(M,T,'25 reuses') = X.L(M,T);
484   REPORT14('25 reuses') = TANKS.L;
485   REPORT16(P,'25 reuses') = OPCOST(P);
486   REPORT11('25 reuses') = REF.L;
487   REPORT12('25 reuses') = OVH.L;
488   REPORT3(P,'25 reuses') = OPCOST(P) + TOTCOST.L ;
489   REPORT8(P,'25 reuse') = (OPCOST(P) + TOTCOST.L)/WT;
490
491
492   OPTION DECIMALS=0 ;
493   DISPLAY REPORT5, REPORT2, REPORT13, REPORT15, REPORT9, REPORT10, REPORT1,
494     REPORT7;
495   DISPLAY REPORT6, REPORT4, REPORT14, REPORT16, REPORT11, REPORT12,
496     REPORT3, REPORT8;
```

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SEALAR SPACE TRANSPORTATION SYSTEM MODEL

SETS

F	FUEL TYPES
M	TYPES OF TANK MATERIALS
P	PORTS
T	TANK TYPES

PARAMETERS

ADD	ADDITIONAL FUEL REQUIRED TO ACCOUNT FOR BOILOFF
AMT	AMOUNT OF FUEL TYPE F REQUIRED FOR 10000 LB PAYLOAD
BOFF	BOIL-OFF ALLOWANCES FOR FUEL TYPE F
BRENT	BARGE RENTAL FEE PER DAY
BSPEED	AVERAGE BARGE SPEED
DESIGN	DESIGN COST FOR TANK T OF MATERIAL TYPE M
DIST	DISTANCE FROM PORT P TO LAUNCH SITE IN MILES
FABRICATE	FABRICATION COST OF TANK T OF MATERIAL M
FREQ	TOTAL AMOUNT OF FUEL REQUIRED FOR PAYLOAD OF WEIGHT WT
FUELCOST	COST OF FUEL FOR PAYLOAD OF WEIGHT WT
INSPECT	INSPECTION TIME FOR TANK T OF MATERIAL TYPE M
MCOST	COST PER POUND OF MATERIAL TYPE M
MISYR	MISSIONS PER YEAR
MWT	WEIGHT OF MATERIAL TYPE M USED IN ONE TANK
NEWAMT	REQUIRED FUEL PLUS ADDITIONAL FUEL
NMTO1	MILES TO RETRIEVE FIRST STAGE
NMTO2	MILES TO RETRIEVE SECOND STAGE
NUM	NUMBER OF SUBCALIBUR ROCKETS
NUMMIS	TOTAL NUMBER OF MISSIONS
OPCOST	TOTAL OPERATING COSTS AT PORT P
OVHEAD	OVERHEAD COST FOR TANK T OF MATERIAL TYPE M
PERS	NUMBER OF PERSONNEL
PERSCOST	PERSONNEL COSTS
PREPRO	PREPRODUCTION COST FOR TANK T OF MATERIAL TYPE M
PRICE	BEST PRICE PER KG OF FUEL F AT PORT P
RATE	RATE PER HOUR FOR INSPECTION OF TYPE M MATERIAL
RD	RESEARCH AND DEVELOPMENT COST PER MISSION FOR TANKS
RDAMT	AMOUNT OF MATERIAL TYPE M USED IN R AND D OF TANK T
RDCOST	RESEARCH AND DEVELOPMENT COST FOR TANK T OF MATERIAL M
RECOVERY	RECOVERY AND WASH OFF COST FOR TYPE M OF TANK T
REFURB	REFURBISHMENT COST FOR TANK T OF MATERIAL M
REPAIR	REPAIR COST FOR TANK T OF MATERIAL TYPE M
REPORT1	PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR
REPORT10	OVERHEAD COSTS PER MISSION
REPORT11	REFURBISHMENT COSTS PER MISSION
REPORT12	OVERHEAD COSTS PER MISSION
REPORT13	TANK COSTS PER MISSION
REPORT14	TANK COSTS PER MISSION
REPORT15	OPERATING COSTS AT PORT P FOR THIS MISSION
REPORT16	OPERATING COSTS AT PORT P FOR THIS MISSION
REPORT2	NUMBER OF TANKS FOR 12 MISSIONS PER YEAR
REPORT3	PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

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SEALAR SPACE TRANSPORTATION SYSTEM MODEL

PARAMETERS (Continued)
REPORT4   NUMBER OF TANKS FOR 72 MISSIONS PER YEAR
REPORT5   RESEARCH AND DEVELOPMENT COSTS PER MISSION
REPORT6   RESEARCH AND DEVELOPMENT COSTS PER MISSION
REPORT7   PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR
REPORT8   PORT COSTS PER LB FOR 72 MISSIONS PER YEAR
REPORT9   REFURBISHMENT COSTS PER MISSION
REUSE   NUMBER OF REUSES OF TANKS
SALARY   AVERAGE ANNUAL SALARY
TANK   NUMBER OF TANKS OF TYPE T REQUIRED PER ROCKET
TDREQ   ADDITIONAL FLUID REQUIREMENTS FOR TIME DELAY
TEST   PROTOTYPE AND TEST COST FOR TANK OF MATERIAL TYPE M
TRANSCOST   COST OF TRANSPORTATION
UNITCOST   UNIT PRODUCTION COST FOR TANK T OF MATERIAL M
UTEST   UNIT TEST COST FOR TANK T OF MATERIAL TYPE M
WT   PAYLOAD WEIGHT

VARIABLES

OVH   TOTAL OVERHEAD COSTS FOR TANKS PER MISSION PER YEAR
REF   TOTAL RECOVERY AND REFURBISHMENT COSTS FOR THIS MISSION
TANKS   COST OF TANKS FOR THIS MISSION
TOTCOST   TOTAL COST OF TANKS
X   NUMBER OF TANKS TYPE T OF MATERIAL M

EQUATIONS

OVERHEAD   TOTAL OVERHEAD COSTS FOR TANKS PER MISSION PER YEAR
REFURBISH   TOTAL RECOVERY AND REFURBISHMENT COSTS FOR THIS MISSION
REQTANKS   NUMBER OF TANKS OF TYPE T REQUIRED FOR THE MISSION
TANKCOST   TOTAL COST OF TANKS
TCOST   COST OF TANKS FOR THIS MISSION

MODELS

SSTS

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APPENDIX B

SEALAR SPACE TRANSPORTATION SYSTEM REPORTS FOR TANK AND OP COSTS

```
----    438 PARAMETER REPORT5       RESEARCH AND DEVELOPMENT COSTS PER MISSION
```

ONE REUSE 754586,   TWO REUSES 754586,   FIVE REUSE 754586,
TEN REUSES 754586,   25 REUSES 754586

```
----    438 PARAMETER REPORT2       NUMBER OF TANKS FOR 12 MISSIONS PER YEAR
```

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 PEUSES
MARAGING.RP1	1	1	1	1	1
MARAGING.LOX1	1	1	1	1	1
MARAGING.LOX2	1	1	1	1	1
MARAGING.LH2	1	1	1	1	1
MARAGING.HEL1	1	1	1	1	1
MARAGING.HEL2	1	1	1	1	1

```
----    438 PARAMETER REPORT13      TANK COSTS PER MISSION
```

ONE REUSE 4945400,   TWO REUSES 2472700,   FIVE REUSE 989080,
TEN REUSES 494540,   25 REUSES 197816

```
----    438 PARAMETER REPORT15      OPERATING COSTS AT PORT P FOR THIS MISSION
```

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

```
----    438 PARAMETER REPORT9       REFURBISHMENT COSTS PER MISSION
```

ONE REUSE 65900,   TWO REUSES 65900,   FIVE REUSE 65900,
TEN REUSES 65900,   25 REUSES 65900

```
----    438 PARAMETER REPORT10      OVERHEAD COSTS PER MISSION
```

ONE REUSE 5833,   TWO REUSES 5833,   FIVE REUSE 5833,
TEN REUSES 5833,   25 REUSES 5833

```
----    438 PARAMETER REPORT1       PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR
```

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	8693665	6220965	4737345	4242805	3946081
SANDIEGO	8517744	6045044	4561424	4066884	3770160
GALVESTON	8550089	6077389	4593769	4099229	3802505
JACKSONVIL	8528987	6056287	4572667	4078127	3781403

SEALAR SPACE TRANSPORTATION SYSTEM REPORTS FOR TANK AND OP COSTS

---- 438 PARAMETER REPORT7   PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	869	622	474	424	395
SANDIEGO	852	605	456	407	377
GALVESTON	855	608	459	410	380
JACKSONVIL	853	606	457	408	378

---- 440 PARAMETER REPORT6   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 754586,   TWO REUSES 754586,   FIVE REUSE 754586,
TEN REUSES 754586,   25 REUSES 754586

---- 440 PARAMETER REPORT4   NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
MARAGING.RP1	1	1	1	1	1
MARAGING.LOX1	1	1	1	1	1
MARAGING.LOX2	1	1	1	1	1
MARAGING.LH2	1	1	1	1	1
MARAGING.HEL1	1	1	1	1	1
MARAGING.HEL2	1	1	1	1	1

---- 440 PARAMETER REPORT14   TANK COSTS PER MISSION

ONE REUSE 4945400,   TWO REUSES 2472700,   FIVE REUSE 989080,
TEN REUSES 494540,   25 REUSES   197816

---- 440 PARAMETER REPORT16   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

---- 440 PARAMETER REPORT11   REFURBISHMENT COSTS PER MISSION

ONE REUSE 65900,   TWO REUSES 65900,   FIVE REUSE 65900,
TEN REUSES 65900,   25 REUSES 65900

---- 440 PARAMETER REPORT12   OVERHEAD COSTS PER MISSION

ONE REUSE 972,   TWO REUSES 972,   FIVE REUSE 972,
TEN REUSES 972,   25 REUSES 972

SEALAR SPACE TRANSPORTATION SYSTEM REPORTS FOR TANK AND OP COSTS

---- 440 PARAMETER REPORT3   PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	8553091	6085391	4601771	4107231	3810507
SANDIEGO	8483880	6011180	4527560	4033020	3736296
GALVESTON	8521273	6048573	4564953	4070413	3773669
JACKSONVIL	8500578	6027878	4544258	4049718	3752994

---- 440 PARAMETER REPORT8   PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	856	609	460	411	381
SANDIEGO	848	601	453	403	374
GALVESTON	852	605	456	407	377
JACKSONVIL	850	603	454	405	375

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APPENDIX C

SSTS TANK AND OP COSTS WHEN PRICE OF MARAGING STEEL IS INCREASED SIGNIFICANTLY

---- 498 PARAMETER REPORT5   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 11747744,   TWO REUSES 11747744,   FIVE REUSE 11747744,
TEN REUSES 11747744,   25 REUSES 11747744

---- 498 PARAMETER REPORT2   NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH.RP1					1
CRYOSTRCH.LOX1	1	1	1	1	1
CRYOSTRCH.LOX2	1	1	1	1	1
CRYOSTRCH.LH2		1	1	1	1
CRYOSTRCH.HEL2				1	1
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				
TITANIUM .HEL1	1	1	1	1	1
TITANIUM .HEL2	1	1	1		

---- 498 PARAMETER REPORT13   TANK COSTS PER MISSION

ONE REUSE 6736800,   TWO REUSES 3375100,   FIVE REUSE 1350040,
TEN REUSES 675970,   25 REUSES 272588

---- 498 PARAMETER REPORT15   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	275726	2757267

---- 498 PARAMETER REPORT9   REFURBISHMENT COSTS PER MISSION

ONE REUSE 83080,   TWO REUSES 72110,   FIVE REUSE 72110,
TEN REUSES 71015,   25 REUSES 65525

---- 498 PARAMETER REPORT10   OVERHEAD COSTS PER MISSION

ONE REUSE 2667,   TWO REUSES 2667,   FIVE REUSE 2667,
TEN REUSES 2792,   25 REUSES 2792

---- 498 PARAMETER REPORT1   PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	21492237	18119567	16094507	15419467	15010595
SANDIEGO	21316315	17943645	15918585	15243545	14834673
GALVESTON	21348661	17975991	15950931	15275891	14867019
JACKSONVIL	21327558	17954888	15929828	15254788	14845916

SSTS TANK AND OP COSTS WHEN PRICE OF MARAGING STEEL IS INCREASED SIGNIFICANTLY

---- 498 PARAMETER REPORT7   PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	2149	1812	1609	1542	1501
SANDIEGO	2132	1794	1592	1524	1483
GALVESTON	2135	1798	1595	1528	1487
JACKSONVIL	2133	1795	1593	1525	1485

---- 500 PARAMETER REPORT6   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 11747744,   TWO REUSES 11747744,   FIVE REUSE 11747744,
TEN REUSES 11747744,   25 REUSES 11747744

· - 500 PARAMETER REPORT4   NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH.RP1					1
CRYOSTRCH.LOX1	1	1	1	1	1
CRYOSTRCH.LOX2	1	1	1	1	1
CRYOSTRCH.LH2		1	1	1	1
CRYOSTRCH.HEL2				1	1
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				
TITANIUM .HEL1	1	1	1	1	1
TITANIUM .HEL2	1	1	1		

---- 500 PARAMETER REPORT14   TANK COSTS PER MISSION

ONE REUSE 6736800,   TWO REUSES 3375100,   FIVE REUSE 1350040,
TEN REUSES 675970,   25 REUSES   272588

---- 500 PARAMETER REPORT16   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

---- 500 PARAMETER REPORT11   REFURBISHMENT COSTS PER MISSION

ONE REUSE 83080,   TWO REUSES 72110,   FIVE REUSE 72110,
TEN REUSES 71015,   25 REUSES 65525

SSTS TANK AND OP COSTS WHEN PRICE OF MARAGING STEEL IS INCREASED SIGNIFICANTLY

---- 500 PARAMETER REPORT12   OVERHEAD COSTS PER MISSION

ONE REUSE 444,   TWO REUSES 444,   FIVE REUSE 444,
TEN REUSES 465,   25 REUSES 465

---- 500 PARAMETER REPORT3   PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	21490014	18117344	16092284	15417140	15008268
SANDIEGO	21314092	17941422	15916362	15241218	14832346
GALVESTON	21346438	17973768	15948708	15273564	14864692
JACKSONVIL	21325335	1795^.	15927605	15252461	14843589

---- 500 PARAMETER REPORT8   PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	2149	1812	1609	1542	1501
SANDIEGO	2131	1794	1592	1524	1483
GALVESTON	2135	1797	1595	1527	1486
JACKSONVIL	2133	1795	1593	1525	1484

APPENDIX D

SSTS TANK AND OP COSTS WHEN COMPOSITES WERE CHEAP AND MARAGING STEEL WAS HIGH

----   443 PARAMETER REPORT5   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 11448899,   TWO REUSES 11448899,   FIVE REUSE 11448899,
TEN REUSES 11448899,   25 REUSES 11448899

----   443 PARAMETER REPORT2   NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH .RP1					1
CRYOSTRCH .LOX2	1	1	1	1	1
CRYOSTRCH .LH2		1	1	1	1
CRYOSTRCH .HEL2					1
COMPOSITES.LOX1	1	1	1	1	1
COMPOSITES.HEL1	1	1	1	1	1
COMPOSITES.HEL2	1	1	1	1	
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				

----   443 PARAMETER REPORT13   TANK COSTS PER MISSION

ONE REUSE 4335500,   TWO REUSES 2174450,   FIVE REUSE 869780,
TEN REUSES 454890,   25 REUSES   178160

----   443 PARAMETER REPORT15   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUCES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

----   443 PARAMETER REPORT9   REFURBISHMENT COSTS PER MISSION

ONE REUSE 100880,   TWO REUSES 89910,   FIVE REUSE 89910,
TEN REUSES 89910,   25 REUSES   81855

----   443 PARAMETER REPORT10   OVERHEAD COSTS PER MISSION

ONE REUSE 7083,   TWO REUSES 7083,   FIVE REUSE 7083,
TEN REUSES 7083,   25 REUSES   6042

----   443 PARAMETER REPORT1   PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	18814308	16642288	15337618	14902728	14636902
SANDIEGO	18638387	16466367	15161697	14726807	14460980
GALVESTON	18670732	16498712	15194042	14759152	14493326
JACKSONVIL	18649630	16477610	15172940	14738050	14472223

SSTS TANK AND OP COSTS WHEN COMPOSITES HERE CHEAP AND MARAGING STEEL HAS HIGH

---- 443 PARAMETER REPORT7   PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	1881	1664	1534	1490	1464
SANDIEGO	1864	1647	1516	1473	1446
GALVESTON	1867	1650	1519	1476	1449
JACKSONVIL	1865	1648	1517	1474	1447

---- 445 PARAMETER REPORT6   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 11448899,   TWO REUSES 11448899,   FIVE REUSE 11448899,
TEN REUSES 11448899,   25 REUSES 11448899

---- 445 PARAMETER REPORT4   NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH .RP1					1
CRYOSTRCH .LOX2	1	1	1	1	1
CRYOSTRCH .LH2		1	1	1	1
CRYOSTRCH .HEL2					1
COMPOSITES.LOX1	1	1	1	1	1
COMPOSITES.HEL1	1	1	1	1	1
COMPOSITES.HEL2	1	1	1	1	
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				

---- 445 PARAMETER REPORT14   TANK COSTS PER MISSION

ONE REUSE 4335500,   TWO REUSES 2174450,   FIVE REUSE 869780,
TEN REUSES 434890,   25 REUSES   178160

---- 445 PARAMETER REPORT16   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

---- 445 PARAMETER REPORT11   REFURBISHMENT COSTS PER MISSION

ONE REUSE 100880,   TWO REUSES 89910,   FIVE REUSE 89910,
TEN REUSES 89910,   25 REUSES   81855

SSTS TANK AND OP COSTS WHEN COMPOSITES WERE CHEAP AND MARAGING STEEL WAS HIGH

----   445 PARAMETER REPORT12   OVERHEAD COSTS PER MISSION

ONE REUSE 1181,   TWO REUSES 1181,   FIVE REUSE 1181,
TEN REUSES 1181,   25 REUSES 1007

----   445 PARAMETER REPORT3   PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	18677693	16505673	15201003	14766113	14501154
SANDIEGO	18603481	16431461	15126791	14691901	14426943
GALVESTON	18640874	16468854	15164184	14729294	14464336
JACKSONVIL	18620180	16448160	15143490	14708600	14443641

----   445 PARAMETER REPORT8   PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	1868	1651	1520	1477	1450
SANDIEGO	1860	1643	1513	1469	1443
GALVESTON	1864	1647	1516	1473	1446
JACKSONVIL	1862	1645	1514	1471	1444

APPENDIX E

SSTS TANK AND OP COSTS WHEN RESEARCH & DEVELOPMENT COSTS ARE FOR TANKS SPECIFIED BY MODEL

---- 443 PARAMETER REPORT5   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE   130042,   TWO REUSES 130042,   FIVE REUSE 130042,
TEN REUSES 130042,   25 REUSES   130042

---- 443 PARAMETER REPORT2   NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
MARAGING.RP1	1	1	1	1	1
MARAGING.LOX1	1	1	1	1	1
MARAGING.LOX2	1	1	1	1	1
MARAGING.LH2	1	1	1	1	1
MARAGING.HEL1	1	1	1	1	1
MARAGING.HEL2	1	1	1	1	1

---- 443 PARAMETER REPORT13   TANK COSTS PER MISSION

ONE REUSE   4945400,   TWO REUSES 2472700,   FIVE REUSE   989080,
TEN REUSES   494540,   25 REUSES   197816

---- 443 PARAMETER REPORT15   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

---- 443 PARAMETER REPORT9   REFURBISHMENT COSTS PER MISSION

ONE REUSE   65900,   TWO REUSES 65900,   FIVE REUSE 65900,
TEN REUSES 65900,   25 REUSES   65900

---- 443 PARAMETER REPORT10   OVERHEAD COSTS PER MISSION

ONE REUSE   5833,   TWO REUSES 5833,   FIVE REUSE 5833,
TEN REUSES 5833,   25 REUSES   5833

---- 443 PARAMETER REPORT1   PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	8069121	5596421	4112801	3618261	3321537
SANDIEGO	7893200	5420500	3936880	3442340	3145616
GALVESTON	7925545	5452845	3969225	3474685	3177961
JACKSONVIL	7904443	5431743	3948123	3453583	3156859

SSTS TANK AND OP COSTS WHEN RESEARCH & DEVELOPMENT COSTS ARE FOR TANKS SPECIFIED BY MODEL

----   443 PARAMETER REPORT7   PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	807	560	411	362	332
SANDIEGO	789	542	394	344	315
GALVESTON	793	545	397	347	318
JACKSONVIL	790	543	395	345	316

----   445 PARAMETER REPORT6   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 130042,   TWO REUSES 130042,   FIVE REUSE 130042,
TEN REUSES 130042,   25 REUSES 130042

----   445 PARAMETER REPORT4   NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
MARAGING.RP1	1	1	1	1	1
MARAGING.LOY1	1	1	1	1	1
MARAGING.LOY2	1	1	1	1	1
MARAGING.LH2	1	1	1	1	1
MARAGING.HEL1	1	1	1	1	1
MARAGING.HEL2	1	1	1	1	1

----   445 PARAMETER REPORT14   TANK COSTS PER MISSION

ONE REUSE 4945400,   TWO REUSES 2472700,   FIVE REUSE 989080,
TEN REUSES 494540,   25 REUSES   197816

----   445 PARAMETER REPORT16   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

----   445 PARAMETER REPORT11   REFURBISHMENT COSTS PER MISSION

ONE REUSE 65900,   TWO REUSES 65900,   FIVE REUSE 65900,
TEN REUSES 65900,   25 REUSES 65900

----   445 PARAMETER REPORT12   OVERHEAD COSTS PER MISSION

ONE REUSE 972,   TWO REUSES 972,   FIVE REUSE 972,
TEN REUSES 972,   25 REUSES 972

CSTS TANK AND OP COSTS WHEN RESEARCH & DEVELOPMENT COSTS ARE FOR TANKS SPECIFIED BY MODEL

----   445 PARAMETER REPORT3   PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	7933547	5460847	3977227	3482687	3185963
SANDIEGO	7859336	5386636	3903016	3408476	3111752
GALVESTON	7396729	5424029	3940409	3445869	3149145
JACKSONVIL	7876034	5403334	3919714	3425174	3128450

----   445 PARAMETER REPORT8   PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	793	546	398	348	319
SANDIEGO	786	539	390	341	311
GALVESTON	790	542	394	345	315
JACKSONVIL	788	540	392	343	313

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS AND MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT5   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 177884,   TWO REUSES 176686,   FIVE REUSE 176686,
TEN REUSES 176686,   25 REUSES 178436

---- 443 PARAMETER REPORT2   NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH.RP1					1
CRYOSTRCH.LOX1	1	1	1	1	1
CRYOSTRCH.LOX2	1	1	1	1	1
CRYOSTRCH.LH2		1	1	1	1
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				
TITANIUM .HEL1	1	1	1	1	1
TITANIUM .HEL2	1	1	1	1	1

---- 443 PARAMETER REPORT13   TANK COSTS PER MISSION

ONE REUSE 6736800,   TWO REUSES 3375100,   FIVE REUSE 1350040,
TEN REUSES 675020,   25 REUSES   272208

---- 443 PARAMETER REPORT15   OPERATI _ COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

---- 443 PARAMETER REPORT9   REFURBISHMENT COSTS PER MISSION

ONE REUSE 83080,   TWO REUSES 72110,   FIVE REUSE 72110,
TEN REUSES 72110,   25 REUSES 66620

---- 443 PARAMETER REPORT10   OVERHEAD COSTS PER MISSION

ONE REUSE 2667,   TWO REUSES 2667,   FIVE REUSE 2667,
TEN REUSES 2667,   25 REUSES 2667

---- 443 PARAMETER REPORT1   PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	9922377	6548509	4523449	3848429	3441877
SANDIEGO	9746455	6372587	4347527	3672507	3265955
GALVESTON	9778801	6404933	4379873	3704853	3298301
JACKSONVIL	9757698	6383830	4358770	3683750	3277198

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS AND MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT7   PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	992	655	452	385	344
SANDIEGO	975	637	435	367	327
GALVESTON	978	640	438	370	330
JACKSONVIL	976	638	436	368	328

---- 445 PARAMETER REPORT6   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 177884,   TWO REUSES 176686,   FIVE REUSE 176686,
TEN REUSES 176686,   25 REUSES 178436

---- 445 PARAMETER REPORT4   NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH.RP1					1
CRYOSTRCH.LOX1	1	1	1	1	1
CRYOSTRCH.LOX2	1	1	1	1	1
CRYOSTRCH.LH2		1	1	1	1
TITANIUM .RP1	1	1	1	1	
TITANIUM .LH2	1				
TITANIUM .HEL1	1	1	1	1	1
TITANIUM .HEL2	1	1	1	1	1

---- 445 PARAMETER REPORT14   TANK COSTS PER MISSION

ONE REUSE 6736300,   TWO REUSES 3375100,   FIVE REUSE 1350040,
TEN REUSES 675020,   25 REUSES   272208

---- 445 PARAMETER REPORT16   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

---- 445 PARAMETER REPORT11   REFURBISHMENT COSTS PER MISSION

ONE REUSE 83080,   TWO REUSES 72110,   FIVE REUSE 72110,
TEN REUSES 72110,   25 REUSES   66620

---- 445 PARAMETER REPORT12   OVERHEAD COSTS PER MISSION

ONE REUSE 444,   TWO REUSES 444,   FIVE REUSE 444,
TEN REUSES 444,   25 REUSES   444

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS AND MARAGING STEEL WAS HIGH

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----    445 PARAMETER REPORT3     PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

              ONE REUSE   TWO REUSES  FIVE REUSE  TEN REUSES   25 REUSES

HONOLULU       9789442     6415574     4390514     3715494     3308942
SA'.DIEGO      9715230     6341362     4316302     3641282     3234730
GALVESTON      9752623     6378755     4353695     3678675     3272123
JACKSONVIL     9731929     6358061     4333001     3657981     3251429


----    445 PARAMETER REPORT8     PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

              ONE REUSE   TWO REUSES  FIVE REUSE  TEN REUSES   25 REUSE

HONOLULU           979         642         439         372         331
SANDIEGO           972         634         432         364         323
GALVESTON          975         638         435         368         327
JACKSONVIL         973         636         433         366         325
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SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS, COMPOSITES WERE LOW & MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT5   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 86005,   TWO REUSES 84807,   FIVE REUSE 62838,
TEN REUSES 62838,   25 REUSES 62838

---- 443 PARAMETER REPORT2   NUMBER OF TANKS FOR 12 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH .LOX2	1	1	1	1	1
CRYOSTRCH .LH2		1	1	1	1
COMPOSITES.RP1			1	1	1
COMPOSITES.LOX1	1	1	1	1	1
COMPOSITES.HEL1	1	1	1	1	1
COMPOSITES.HEL2	1	1	1	1	1
TITANIUM .RP1	1	1			
TITANIUM .LH2	1				

---- 443 PARAMETER REPORT13   TANK COSTS PER MISSION

ONE REUSE 4335500,   TWO REUSES 2174450,   FIVE REUSE 875320,
TEN REUSES 437660,   25 REUSES   175064

---- 443 PARAMETER REPORT15   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2921946	2921946	2921946	2921946	2921946
SANDIEGO	2746024	2746024	2746024	2746024	2746024
GALVESTON	2778370	2778370	2778370	2778370	2778370
JACKSONVIL	2757267	2757267	2757267	2757267	2757267

---- 443 PARAMETER REPORT9   REFURBISHMENT COSTS PER MISSION

ONE REUSE 100880,   TWO REUSES 89910,   FIVE REUSE 96550,
TEN REUSES 96550,   25 REUSES   96550

---- 443 PARAMETER REPORT10   OVERHEAD COSTS PER MISSION

ONE REUSE 7083,   TWO REUSES 7083,   FIVE REUSE 11250,
TEN REUSES 11250,   25 REUSES 11250

---- 443 PARAMETER REPORT1   PORT COSTS PER MISSION FOR 12 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	7451414	5278196	3967904	3530244	3267648
SANDIEGO	7275493	5102275	3791982	3354322	3091726
GALVESTON	7307838	5134620	3824328	3386668	3124072
JACKSONVIL	7286736	5113518	3803225	3365565	3102969

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS, COMPOSITES WERE LOW & MARAGING STEEL WAS HIGH

---- 443 PARAMETER REPORT7   PORT COSTS PER LB FOR TWELVE MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	745	528	397	353	327
SANDIEGO	728	510	379	335	309
GALVESTON	731	513	382	339	312
JACKSONVIL	729	511	380	337	310

---- 445 PARAMETER REPORT6   RESEARCH AND DEVELOPMENT COSTS PER MISSION

ONE REUSE 86005,   TWO REUSES 62838,   FIVE REUSE 62838,
TEN REUSES 62838,   25 REUSES 62838

---- 445 PARAMETER REPORT4   NUMBER OF TANKS FOR 72 MISSIONS PER YEAR

	ONE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
CRYOSTRCH .LOX2	1	1	1	1	1
CRYOSTRCH .LH2		1	1	1	1
COMPOSITES.RP1		1	1	1	1
COMPOSITES.LOX1	1	1	1	1	1
COMPOSITES.HEL1	1	1	1	1	1
COMPOSITES.HEL2	1	1	1	1	1
TITANIUM .RP1	1				
TITANIUM .LH2	1				

---- 445 PARAMETER REPORT14   TANK COSTS PER MISSION

ONE REUSE 4335500,   TWO REUSES 2188300,   FIVE REUSE 875320,
TEN REUSES 437660,   25 REUSES 175064

---- 445 PARAMETER REPORT16   OPERATING COSTS AT PORT P FOR THIS MISSION

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	2791233	2791233	2791233	2791233	2791233
SANDIEGO	2717022	2717022	2717022	2717022	2717022
GALVESTON	2754415	2754415	2754415	2754415	2754415
JACKSONVIL	2733720	2733720	2733720	2733720	2733720

---- 445 PARAMETER REPORT11   REFURBISHMENT COSTS PER MISSION

ONE REUSE 100880,   TWO REUSES 96550,   FIVE REUSE 96550,
TEN REUSES 96550,   25 REUSES 96550

---- 445 PARAMETER REPORT12   OVERHEAD COSTS PER MISSION

ONE REUSE 1181,   TWO REUSES 1875,   FIVE REUSE 1875,
TEN REUSES 1875,   25 REUSES 1875

SSTS COSTS WHEN R&D WAS FOR SPECIFIED TANKS, COMPOSITES WERE LOW & MARAGING STEEL HAS HIGH

---- 445 PARAMETER REPORT3   PORT COSTS PER MISSION FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSES
HONOLULU	7314799	5140796	3827816	3390156	3127560
SANDIEGO	7240587	5066585	3753605	3315945	3053349
GALVESTON	7277980	5103978	3790998	3353338	3090742
JACKSONVIL	7257286	5083283	3770303	3332643	3070047

---- 445 PARAMETER REPORT8   PORT COSTS PER LB FOR 72 MISSIONS PER YEAR

	ONE REUSE	TWO REUSES	FIVE REUSE	TEN REUSES	25 REUSE
HONOLULU	731	514	383	339	313
SANDIEGO	724	507	375	332	305
GALVESTON	728	510	379	335	309
JACKSONVIL	726	508	377	333	307

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